AD

USAAMRDL TECHNICAL REPORT 72-22

INVESTIGATION OF THE SPEED BRAKES ON THE S-67 AIRCRAFT

By

N. F. K. Kefford

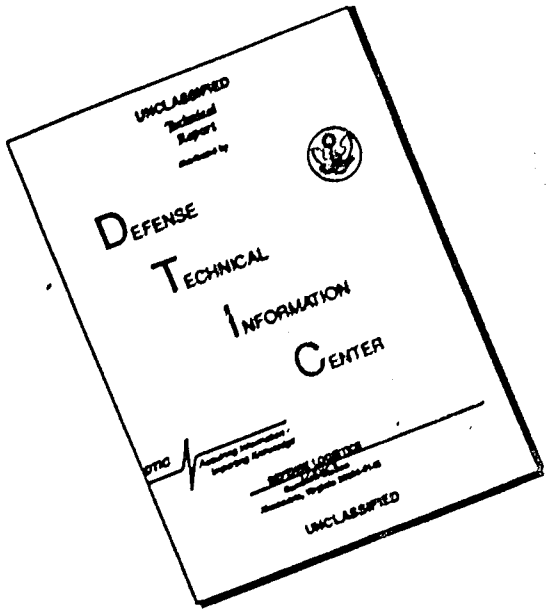
May 1972

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

CONTRACT DAAJ02-71-C-0009
UNITED AIRCRAFT CORPORATION
SIKORSKY AIRCRAFT DIVISION
STRATFORD, CONNECTICUT

Approved for public release; distribution unlimited.

DISCLAIMER NOTICE



THIS DOCUMENT IS BEST QUALITY AVAILABLE. THE COPY FURNISHED TO DTIC CONTAINED A SIGNIFICANT NUMBER OF PAGES WHICH DO NOT REPRODUCE LEGIBLY.

DISCLAIMERS

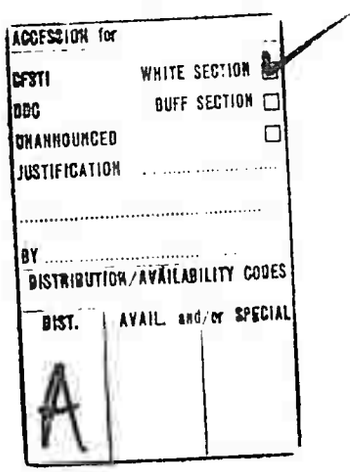
The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission, to manufacture, use, or sell any patented invention that may in any way be related thereto.

Trade names cited in this report do not constitute an official endorsement or approval of the use of such commercial hardware or software.

DISPOSITION INSTRUCTIONS

Destroy this report when no longer needed. Do not return it to the originator.



Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Sikorsky Aircraft Division United Aircraft Corporation Stratford, Connecticut	Unclassified 2b. GROUP

3. REPORT TITLE

INVESTIGATION OF THE SPEED BRAKES ON THE S-67 AIRCRAFT

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (First name, middle initial, last name)

N.F.K. Kefford

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
April 1972	57	4

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
DAAJ02-71-C-0009 b. PROJECT NO. c. Task 1F163204D15704 d.	USAAMRDL Technical Report 72-22 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) SER-67007

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Eustis Directorate U.S. Army Air Mobility R&D Laboratory Fort Eustis, Virginia

13. ABSTRACT

Under Contract DAAJ02-71-C-0009, Sikorsky Aircraft conducted flight tests and computer simulations to evaluate speed brakes for a winged helicopter.

The flight test program established the effectiveness of wing-mounted speed brakes for increasing dive angle, deceleration capability, and maneuverability of the Sikorsky S-67. In the configuration tested, six brake surfaces operated together to increase aircraft drag by 155% while reducing wing lift. With these speed brakes, dive angles cound be increased f m 5 to 7 degrees at 140 knots dependent upon the initial dive angle. At 160 knots, the increase in dive angle varies from 8 to 9 degrees. These increases in aircraft dive angle due to speed brake extension can be further increased by allowing the aircraft to accelerate during the dive.

Dive characteristics with and without speed brakes extended were obtained. A dive envelope defined by control and airframe stress limits was established that provided a broad dive envelope of forward speed and collective settings to achieve various dive angles.

Above dive speeds of 120 knots, the brakes caused a decrease in fuselage attitude to the flight path of 4 to 5 degrees, for a given dive angle. This, coupled with the steeper dive angles, improves the aircraft's capability as a weapons platform.

Speed brakes enabled constant-altitude deceleration from 180 to 140 knots in 9 seconds as compared to 24 seconds with a clean wing.

The computer simulation program examined increased brake area, variable stabilator bias angle, and the consequences of asymmetric brake deployment. Steady dive angles of 30 degrees or more were possible with increased brake area. Following any configuration of asymmetric brake deployment, there was always sufficient roll control power to restore and hold trim, although some deceleration occurred due to collective and/or power limits.

DD FORM 1 NOV 68 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Helicopter						
Winged Helicopter						
Sikorsky S-67						
Aerodynamics						
Dive						
Deceleration						
Maneuverability						
Speed Brakes						

DEPARTMENT OF THE ARMY
U. S. ARMY AIR MOBILITY RESEARCH & DEVELOPMENT LABORATORY
EUSTIS DIRECTORATE
FORT EUSTIS, VIRGINIA 23604

This report was prepared by United Aircraft Corporation, Sikorsky Aircraft Division, under Contract DAAJ02-71-C-0009.

The program was a flight investigation of wing-mounted speed brakes as installed on the S-67 winged helicopter. A computer simulation study was included to determine the effects of increased brake area, variable stabilator bias angle, and asymmetric brake deployment. This program is one of four flight investigations conducted on the S-67 winged helicopter. The other three flight investigations were concerned with a stabilator, a force-feel control system, and aircraft maneuverability.

The wing-mounted speed brakes on the S-67 aircraft increase the dive angle and reduce the fuselage attitude relative to the flight path. At 140 knots airspeed, the increase in dive angle varies from 5 to 7 degrees dependent upon the initial dive angle. At 160 knots, the increase in dive angle varies from 8 to 9 degrees. The aircraft dive angle may be further increased by allowing the aircraft to accelerate during the dive. The amount of reduction in fuselage angle relative to the flight path varies from 4 to 5 degrees for all airspeeds above 120 knots. The speed brakes enable the S-67 aircraft to be decelerated in level flight from 180 to 140 knots in 9 seconds as compared to 24 seconds without the use of brakes.

The report has been reviewed by this Directorate and is technically correct.

This program was conducted under the technical management of Mr. R. C. Dumond of the Applied Aeronautics Division.

Task 1F163204D15704
Contract DAAJ02-71-C-0009
USAAMRDL Technical Report 72-22
May 1972

INVESTIGATION OF THE SPEED BRAKES ON THE S-67 AIRCRAFT

SER-67007

by

N. F. K. Kefford

Prepared by

United Aircraft Corporation
Sikorsky Aircraft Division
Stratford, Connecticut

for

EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
FORT EUSTIS, VIRGINIA

ABSTRACT

Under Contract DAAJ02-71-C-0009, Sikorsky Aircraft conducted flight tests and computer simulations to evaluate speed brakes for a winged helicopter.

The flight test program established the effectiveness of wing-mounted speed brakes for increasing dive angle, deceleration capability, and maneuverability of the Sikorsky S-67. In the configuration tested, six brake surfaces operated together to increase aircraft drag by 155% while reducing wing lift. With these speed brakes, dive angles could be increased from 5 to 7 degrees at 140 knots dependent upon the initial dive angle. At 160 knots, the increase in dive angle varies from 8 to 9 degrees. These increases in aircraft dive angle due to speed brake extension can be further increased by allowing the aircraft to accelerate during the dive.

Dive characteristics with and without speed brakes extended were obtained. A dive envelope defined by control and airframe stress limits was established that provided a broad dive envelope of forward speed and collective settings to achieve various dive angles.

Above dive speeds of 120 knots, the brakes caused a decrease in fuselage attitude to the flight path of 4 to 5 degrees, for a given dive angle. This, coupled with the steeper dive angles, improves the aircraft's capability as a weapons platform.

Speed brakes enabled constant-altitude deceleration from 180 to 140 knots in 9 seconds as compared to 24 seconds with a clean wing.

The computer simulation program examined increased brake area, variable stabilator bias angle, and the consequences of asymmetric brake deployment. Steady dive angles of 30 degrees or more were possible with increased brake area. Following any configuration of asymmetric brake deployment, there was always sufficient roll control power to restore and hold trim, although some deceleration occurred due to collective and/or power limits.

FOREWORD

This report presents results of flight tests and computer simulations to investigate the effectiveness of speed brakes for increasing dive angle, deceleration capability, and maneuverability of the S-67 aircraft. This program is part of a four-phase investigation of the flight characteristics of the S-67 aircraft as a representative high-speed winged helicopter. Investigations of the stabilator, aircraft maneuverability, and a Feel Augmentation System (FAS) are also part of the flight investigation of the S-67. The FAS is a system to provide "force-feel" in pitch.

The work was performed by the Sikorsky Aircraft Division of United Aircraft Corporation for the U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, under Contract DAAJ02-71-C-0009, DA Task 1F163204D15704. Mr. R. C. Dumond was the Army technical representative.

Preceding page blank

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF SYMBOLS

A_{1_s}	lateral cyclic control, %
B_{1_s}	longitudinal cyclic control, %
i_t	stabilator incidence angle, deg
N_R	main rotor speed, rpm
Q_E	required engine torque, %
ROD	rate of descent, fpm
SHP	required shaft horsepower, hp
V	forward speed, kt
V_{max}	maximum level-flight forward speed, kt
α_f	fuselage angle of attack, deg
β_f	fuselage sideslip angle, deg
γ	dive angle, deg
θ_{TR}	tail rotor blade pitch, deg
θ_f	fuselage pitch attitude, deg
θ_o	main rotor collective control, %
θ_{cuff}	main rotor collective blade pitch, deg
ϕ_f	fuselage roll attitude, deg

INTRODUCTION

Experience with high-performance helicopters has indicated that aerodynamic speed brakes would improve control characteristics and maneuverability. They should reduce aircraft acceleration in a dive as well as reduce wing lift. This would permit steeper dives and rapid decelerations.

Wind tunnel testing of the aerodynamic effects of speed brakes resulted in the present arrangement of six unperforated panels mounted on the wings of the S-67 aircraft.

The speed brakes on the S-67 aircraft were evaluated in flight tests to determine their effectiveness for increasing dive angle, deceleration capability and maneuverability on a high-speed winged helicopter. The test results were correlated with a computer simulation study, and the simulation was used to predict the effects of different brake areas, stabilator bias angle and asymmetric brake deployment.

DESCRIPTION OF AIRCRAFT

The S-67 demonstrator is a high-speed derivative of the Sikorsky SH-3D helicopter. A view of the aircraft is presented in Figure 1. The low-drag airframe was designed to meet requirements of an attack mission. The cockpit is arranged in tandem, with the gunner in the forward seat and the pilot in the aft, elevated seat. The pilot has visibility down to minus 15 degrees over the nose. Two T58-GE-5 engines are mounted in the main rotor pylon above the fuselage center section.

Main rotor hub, tail rotor, drive system, and transmission systems are all SH-3D dynamic components. The main rotor has five S-61F blades, each with a twist of -4 degrees. The 22-inch blade tips are swept back 20 degrees to delay tip Mach number effects. The control system uses SH-3D components and the CH-54 automatic flight control system.

The fixed-wing type control surfaces include a stabilator, a fixed vertical stabilizer, and sponsons with stub wings for additional lift . The tail wheel is attached to the base of the ventral fin, and the retractable main landing gear is housed in the wing. The wing panels have speed brakes to control dive angle and increase deceleration capability. Flight control sensitivities are listed in the table below.

FLIGHT CONTROL SENSITIVITIES

	Servo Travel per Inch (%)	Blade Pitch per Inch (%)	Stick/Pedal Travel (in.)	Blade Pitch Travel (deg)
Longitudinal Cyclic	7.2	1.7	14	24
Lateral Cyclic	7.2	1.4	14	16
Pedals	24.6*	7.75 (Tail Rotor)	4.07*	31.5 (Tail Rotor)
Collective	10.5	1.7	9.5	16

* Working range, at constant collective

Principal dimensions and general data for the S-67 aircraft are as follows:

Main Rotor

Diameter	62 ft
Normal Tip Speed (104% N_R)	686 ft/sec
Disc Area	3019 ft^2
Solidity	0.0781
Number of Blades	5
Blade Chord	1.52 ft
Blade Twist	-4 deg
Airfoil Section	NACA 0012 MOD
Articulation	Full Flapping and Lagging
Tip Sweep	20 deg

Tail Rotor

Diameter	10 ft 4 in.*
Tip Speed	700 ft/sec
Disc Area	83.9 ft^2
Solidity	0.1885
Number of Blades	5
Blade Chord	0.612 ft
Blade Twist	0 deg
Airfoil Section	NACA 0012 MOD
Pitch Flap Coupling	45 deg

* During flight tests, diameter was increased 3 in. to 10 ft. 7 in. to increase lateral low-speed flight capability.

Fuselage	
Overall Length	64 ft 1 in.
Overall Height	16 ft 3 in.
Overall Width	27 ft 4 in.
Wheel Tread	7 ft
Wheel Base	36 ft 2 in.
Stabilator	
Root Chord	4 ft 2 in.
Tip Chord	2 ft
Taper Ratio	0.48
Area	50 ft^2
Span	15 ft 6 in.
Aspect Ratio	4.8
Airfoil (Root)	NACA 0015
Airfoil (Tip)	NACA 0012
Vertical Fin	
Root Chord	7 ft 6 in.
Tip Chord (Upper)	2 ft 10 in.
Tip Chord (Lower)	3 ft 9 in.
Taper Ratio (Upper)	0.62
Taper Ratio (Lower)	0.5
Total Area	68.7 ft^2
Aspect Ratio	2.65
Airfoil Section	NACA 4415
Wing	
Root Chord	4 ft 6 in.
Tip Chord	1 ft 11.5 in.
Overall Span	27 ft 4 in.
Total Exposed Area	58 ft^2
Incidence	8 deg
Dihedral	10 deg
Quarter Chord Sweep	10 deg 45 min
Taper Ratio (Exposed)	0.44
Aspect Ratio	8.0

Wing (cont'd)	
Airfoil Section, Root	NACA 4415
Airfoil Section, Tip	NACA 4412
Propulsion System	
Engines	Two T58-GE-5
Takeoff Power (Each)	1500 HP
Military Power	1400 HP
Normal Power	1250 HP
Transmission Rating	2800 HP (111% engine torque)
Loading Conditions	
Empty Weight*	10900 lb
Maximum Gross Weight Flown	18000 lb
Maximum Gross Weight Capability	21800 lb
Center-of-Gravity Range	258 in. to 276 in.

*Aircraft less fuel, payload, and crew.

THE S-67 SPEED BRAKES

Initial wind tunnel testing of a one-twelfth scale model of the S-67 evaluated an aerodynamic braking surface attached to the main landing gear (Reference 1). Evaluation of other speed brake locations (fuselage, wing, and ventral fin) indicated that wing-mounted surfaces were the most effective. Wind tunnel data predicted an increase of 1.57 in total aircraft drag at zero fuselage incidence. Moreover, wing lift could be reduced for better autorotation characteristics, and for roll control through asymmetric deployment.

Figure 3 shows the location and dimensions of the S-67 speed brakes. Figures 4 and 4 show in-flight front views of the aircraft clean and with brakes extended. The unperforated brake panels lie flush with the wing surface under normal flight conditions, and extend to a position at right angles to the wing chordline. All brake surfaces are actuated by a single hydraulic actuator. Normal time for opening or closing brakes is 1.6 seconds. The actuator control is on the pilot's collective stick, and the emergency retract switch is on the emergency panel (Figure 6).

Wind tunnel data are presented in Appendix I, showing the effects of the wing and speed brakes on total aircraft lift, pitching moment, and drag, as a function of fuselage attitude, α_F, relative to the free stream.

FLIGHT TEST CONDITIONS

LOADING

Listed below are the combinations of gross weight [illegible] locations that were flown. A forward center of gravity, at [illegible] weight, was not flown because it could only be [illegible] load. However, this loading condition was investigated in the [illegible] study.

Load condition	Gross weight	[illegible]
#1	[illegible]	
#2	14,500	%
#3	17,300	%

FLIGHT

In-flight gross weight varied [illegible] altitude of 3'00 feet. For the high descent rate [illegible] study, it was necessary to commence partial power [illegible] altitude of 6000 feet.

STABILATOR BIAS ANGLE

The stabilator bias angle of [illegible] for [illegible] for level flight with speed brakes retracted. This [illegible] overall minimum level of flagging and pitch force gradients, adequate longitudinal control margin, and a [illegible] preserve positive wing lift at high speeds. [illegible] the effects of stabilator bias angle.

RESULTS AND DISCUSSION

LEVEL FLIGHT

Figures [illegible], [illegible], and [illegible] compare control positions and aircraft attitudes with and without speed brakes extended. When the speed brakes are extended, a nose-down pitching moment results. To correct for this, changes in longitudinal cyclic pitch of less than [illegible]% are required. To compensate for the loss in wing lift, collective pitch is increased.

DIVE ANGLE AND FUSELAGE ANGLE OF ATTACK

At speeds between [illegible] knots and V_{max}, dives were made for at least three engine torque settings for each dive speed: the torque that would be required for level flight, the minimum torque to maintain [illegible]% N_R, and an intermediate torque setting. Thus, values of engine torque versus forward speed were obtained at constant dive angle or constant fuselage angle of attack. Figures [illegible]a, [illegible]a, and [illegible]a show dive charts for the [illegible]-lb aft load condition [illegible] with speed brakes extended, and the [illegible]-lb aft load condition [illegible] with and without speed brakes extended. Figures [illegible]a and [illegible] show schematically the values of [illegible], θ_F, and α_F for maximum dive angle at a flight speed of [illegible] knots, [illegible] with speed brakes retracted and extended. Figure [illegible] shows the relationship between fuselage angle of attack and dive angle.

Knowledge and control of the fuselage attitude to flight path, α_F, is important if the pilot is required to direct a weapon or sensing device, fixed to the aircraft, toward some point on the ground. The dive charts derived from flight test data, in Figures [illegible]a, [illegible]a, and [illegible]a, show considerable variation in α_F. This angle becomes as high as [illegible] degrees nose up for the steepest dives as the rotor approaches autorotation. These lines of constant α_F were developed from test data points by cross plotting from curves of α_F versus θ_F at constant flight speed, as illustrated in Figure [illegible].

It is desirable to limit the variation of α_F as much as possible and in particular to prevent its building in steep dives, even with aft cg location, to provide the pilot greater visibility over the nose. A comparison of Figures [illegible]a and [illegible]a shows that, for a given dive angle and flight speed, fuselage angle of attack can be significantly reduced by the speed brakes. Figure [illegible] shows α_F versus dive angle at a speed of [illegible] knots with and without brakes extended, showing that α_F is decreased by about [illegible] degrees at any given dive angle. On the other hand, the brakes enable a [illegible]-degree steeper dive at the same α_F and forward speed. The reduction in fuselage angle of attack and the increase in dive angle due to the speed brakes improve the aircraft's capability as a weapons platform.

The dive charts, Figures [illegible], [illegible], [illegible], and 10a, also show that [illegible] up to almost [illegible] knots for [illegible] with [illegible] flight [illegible] possible, therefore, [illegible] directly [illegible] this speed range.

Because the [illegible] retracted were not fully investigated in flight [illegible], dive performance with and without brakes extended at this [illegible] was obtained by means of the simulator program. These results are shown in Figures [illegible] and [illegible]. The correlation of flight test data with the simulator is discussed in Appendix II. [illegible] was experienced [illegible] the brakes-extended case in simultaneously correlating flight test data with simulated data for engine power, control angles, and aircraft attitudes. For this reason, engine power in Figure [illegible] is low by as much as [illegible] %.

Engine torque [illegible] to be a function of [illegible] pitch for all forward speeds, as shown for the [illegible] in Figure [illegible]. Figure [illegible] shows [illegible] of dive angle flight test data with speed brakes extended. The [illegible] speeds in Figures [illegible], [illegible], and [illegible] are average calibrated airspeeds over each group of test points at nominally constant speed.

DIVE ENVELOPE

Flight test results also established a dive envelope defined by stress and controllability limits, which are discussed below. Data were not taken above the limit speeds shown in Figures [illegible], [illegible], and [illegible]. Figures [illegible], [illegible], and [illegible] show how the individual boundaries [illegible] for the accompanying dive charts of Figures [illegible], [illegible], and 11a. By [illegible] of [illegible] degrees is possible at a flight speed of [illegible] knots, with a maximum dive angle retracted. With brakes extended, Figure 11a, the maximum dive angle is [illegible] degrees, also at [illegible] knots. From Figures [illegible] and 11a, at the lighter gross weight but same [illegible], dive angles are generally about [illegible] degree less, at the same speed and engine [illegible], and [illegible] is about [illegible] degrees less.

In all cases above, dives are at [illegible] airspeed with even steeper dives feasible if the aircraft is permitted to accelerate. The limitations that define the envelope are identified in the following sections, and methods are recommended for expanding the envelope.

Dive angles steeper than those achieved within the established dive envelope are desirable. The effect of added brake area is discussed. [illegible] simulation study [illegible] results predict that a [illegible] degree dive [illegible] with twice the existing brake area, [illegible] the present brakes [illegible] control and [illegible] restraints [illegible] eliminated.

Maximum Engine Torque Limit

An engine output power limit [illegible] is imposed because of the transmission rating. This [illegible] 100% engine torque.

Minimum Engine Torque Limit

As dive angle during flight tests increased for a constant forward speed, the main rotor tended to [illegible]. A minimum engine torque limit existed, below which the main rotor [illegible] was not sufficient to maintain [illegible], and the rotor [illegible]. [illegible] this was zero torque, or true autorotation. Control of the aircraft was difficult in this flight regime [illegible]. A [illegible] would place the rotor in autorotation [illegible]. The aircraft [illegible], and excessive lateral control was required. [illegible] difficulties in this regime are [illegible] at the high angles of attack [illegible] degrees.

The [illegible] boundary lines of figures [illegible] weight, and [illegible], as [illegible], the forward speed at [illegible] engine torque at which the main rotor [illegible] by extending the speed brakes, this [illegible]. [illegible] forward speed for [illegible] extending the brakes [illegible] lift.

Main Rotor [illegible]

At high forward speed [illegible] main rotor [illegible] approached [illegible] limit with the speed brakes extended. This [illegible] affected the [illegible] at the [illegible] gross weight. [illegible] with brakes retracted [illegible].

[illegible]

With speed brakes extended, [illegible] was [illegible] speed at [illegible] brakes extended [illegible] of gross weight.

[illegible]

Lack of Right Pedal Control

The [illegible] has a cambered vertical tail surface to reduce tail rotor thrust requirements in high-speed level flight. As the aircraft accelerates in a dive and main rotor torque is reduced, more right pedal is required to offset the side force caused by the vertical tail surface. Referring to Figure [illegible], as engine torque is decreased at constant airspeed, the tail rotor blade pitch angle approaches the negative limit of -7 degrees to maintain trim. Reference [illegible] specifies a control margin of 10% of travel, so that tail rotor blade angle should not exceed -4 degrees.

This limitation may be eased by extending the tail rotor negative pitch limit, if no undesirable tail rotor instabilities develop at high negative blade pitch. Alternatively, the camber of the vertical fin might be reduced. This would lead to greater tail rotor thrust in level flight, with associated penalties in forward speed capability and tail rotor stresses. Incorporation of a rudder would eliminate all restraints on the yaw control system.

SPEED BRAKE EXTENSION AND RETRACTION, [illegible] FLIGHT

The aircraft transient responses to speed brake extension with fixed controls were obtained at speeds from [illegible] to [illegible] knots. Figure [illegible] shows time histories for a speed of [illegible] knots. The nose-down pitching moment and loss of wing lift as brakes are extended cause a descent, and after [illegible] seconds the aircraft approaches [illegible] degrees nose-down in pitch and about [illegible] degrees left in roll. The transient response of speed brake retraction during a steady dive results in a nose-up pitching moment that improves the "pull-out" capability of the aircraft.

DECELERATION AND TURN

Decelerations from [illegible] knots with speed brakes retracted and extended were performed at constant altitude (within [illegible] feet). Entry speed was [illegible] knots, and exit speed was [illegible] knots. Figure [illegible] shows time histories of the deceleration with speed brakes retracted. Because of the constant altitude constraint, aft longitudinal stick movement was gradual, so that [illegible] wing lift as the aircraft pitched up [illegible] be balanced by reducing [illegible] dive. Total time for the maneuver was [illegible] seconds. Figure [illegible] presents data with speed brakes extended. [illegible] This was achieved with aft [illegible], and the maneuver was [illegible] terminated after [illegible] and [illegible] dive. [illegible] was [illegible] seconds. [illegible] were also performed [illegible] [illegible]-degree turn, with [illegible] speed brakes, maintaining altitude [illegible] to derive maximum turn rate, and [illegible]. Entry speed was [illegible] knots, and exit speed was [illegible] knots. [illegible] angles of [illegible] degrees were reached at a peak load factor of [illegible]. [illegible] was about [illegible] seconds. Mean values for the [illegible]-degree turn were [illegible].

One decelerating left turn was performed from 160 knots to 100 knots, using speed brakes. Deceleration time was 10.6 seconds, including a 1.2-second delay after brake extension before rolling into the turn. Brake retraction was initiated after passing 60-degree bank, which increased pitch rate and load factor. Thereafter, aft cyclic and down collective were employed to complete the maneuver. Mean turn radius was 530 feet. Main rotor pushrod loads were at approximately the same level as on previous turns, but stationary control loads were 50-60% higher.

COMPUTER SIMULATION STUDY

Appendix II describes the computer simulation and shows the comparison of simulation data with flight test data. The simulation was used to predict the effects on dive characteristics of increased brake effectiveness and stabilator bias angle, and to briefly study asymmetric brake deployment. The light aft load condition (2) was used, with a stabilator bias angle of 2.5 degrees.

Increased Brake Effectiveness

Figures 14 and 15, previously mentioned, show dive angle and fuselage angle of attack information developed at the 14,800-lb aft (#2) load condition with and without speed brakes. Figures 15 and 22 illustrate the effects of increased brake effectiveness. Additional brake area should be located on the lower ventral fin, where drag forces would align the airframe to the flight path and turbulence would not impinge on any control surfaces. The simulation results show that a dive angle of 30 degrees is possible at 160 knots. Also, the increased brake area further reduces variation in fuselage angle of attack.

Effect of Stabilator Bias Angle

The fuselage attitude, θ_F, was nose up relative to the flight path in a trimmed dive and varied with speed and rate of descent, reaching about 15 degrees at minimum torque. The speed brakes reduced angle of attack by up to 4 degrees (Figure 14) at a given dive angle and speed, but greater pitch control can be obtained by varying stabilator bias angle.

The dive characteristics were established using the simulator with a stabilator bias angle of 5 degrees leading edge up, relative to the neutral position, rather than the 2.5-degree flight test bias angle, to determine any significant change in angle of attack. From Figures 15 and 23, angle of attack is reduced by as much as 4 degrees when stabilator bias is increased from 2.5 to 5 degrees.

Asymmetric Deployment

A short study was conducted to predict the consequences of asymmetric speed brake deployment due to actuator malfunction. The simulator was used to determine controllability in high-speed level flight with every configuration of extended brake surfaces. Identification of the six brake surfaces is consistent with the original wind tunnel nomenclature Reference 1, and is shown in Figure 24.

Because of the asymmetry of lateral/directional control, the ability to trim the aircraft differs when considering left or right brake extensions. The simulations showed that when brakes are asymmetrically deployed, at forward speeds up to 180 knots, there is always sufficient roll control power to retrim the aircraft, although some deceleration will occur due to available power and/or collective limits. For example, if surfaces 1, 2, and 5 are opened at a forward speed of 180 knots, while 3, 4, and 6 remain closed, the aircraft will decelerate to about 160 knots because of the engine power limit, with the pilot able to restore and hold the aircraft at zero roll angle. At entry speeds below 145 knots, trim can be restored at the same speed following any configuration of speed brake deployment.

CONCLUSIONS

The wing-mounted speed brakes on the S-67 aircraft increase dive angle and reduce the fuselage attitude relative to the flight path (fuselage angle of attack). They permit increases in dive angles from 5 to 7 degrees at 140 knots dependent upon the initial dive angle. At 160 knots, the increase in dive angle varies from 8 to 9 degrees. The increases in aircraft dive angle due to speed brake extension can be further increased if the aircraft is allowed to accelerate in the dive. For dive speeds greater than 120 knots, the fuselage angle of attack is reduced 4 to 5 degrees by extending the speed brakes. The increase in dive angle and/or the reduction in fuselage angle of attack while maintaining airspeed by the use of speed brakes improve the S-67 aircraft's capability as a weapons platform.

LITERATURE CITED

1. Gifford, J. A., ONE-TWELFTH SCALE WIND TUNNEL TESTS ON THE AH-3 (S-67) DEMONSTRATOR AIRCRAFT, SER-67000, Sikorsky Aircraft Division of United Aircraft Corporation, Stratford, Connecticut, April 1970.

2. Kaplita, T. T., S-67 STABILATOR INVESTIGATION, SER-67006, Sikorsky Aircraft Division of United Aircraft Corporation, Stratford, Connecticut, June 1971.

3. GENERAL REQUIREMENTS FOR HELICOPTER FLYING AND GROUND HANDLING QUALITIES, MIL-H-8501A, Amendment 1, April 1962.

4. Corso, J. J., and Kaplita, T. T., GENERAL HELICOPTER SIMULATION PROGRAM, SER 50542, Sikorsky Aircraft Division of United Aircraft Corporation, Stratford, Connecticut, May 1968.

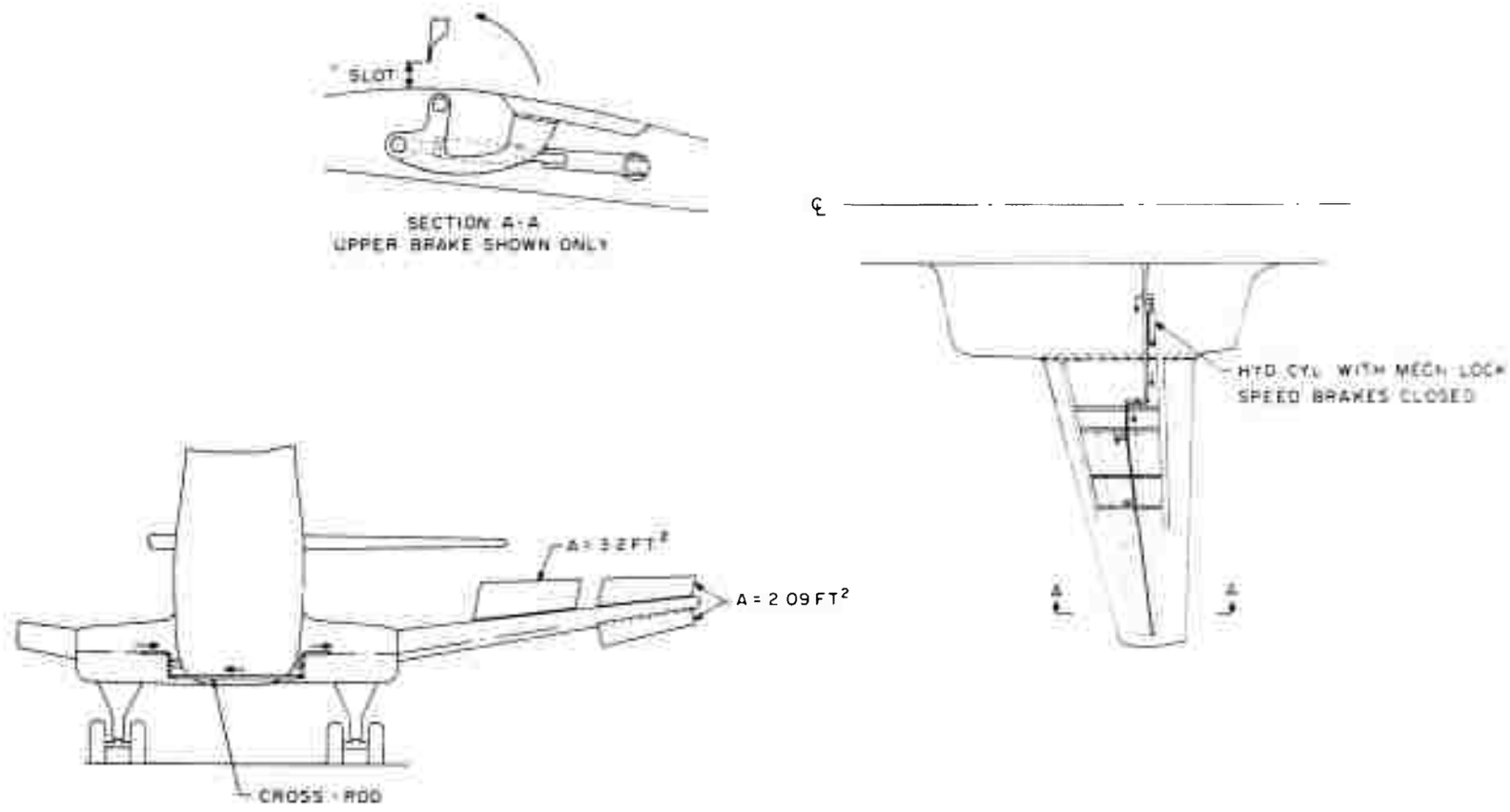


Figure 2. Speed Brake Areas and Locations.

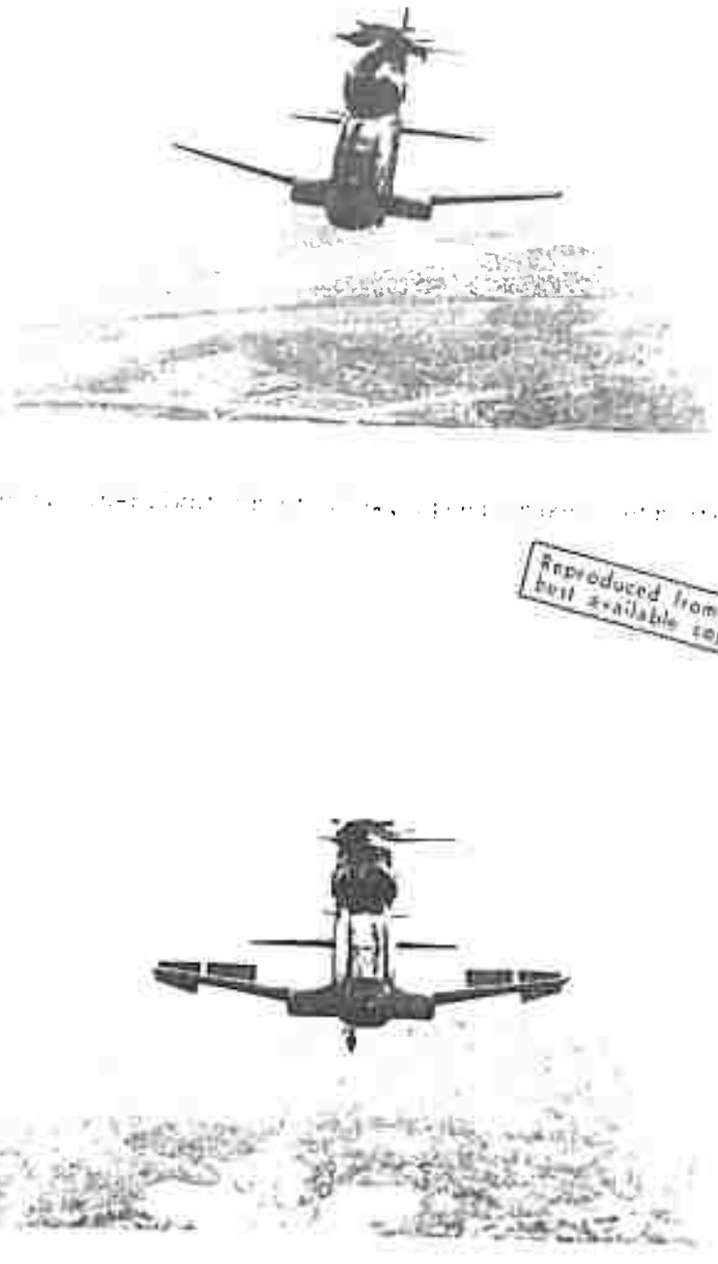
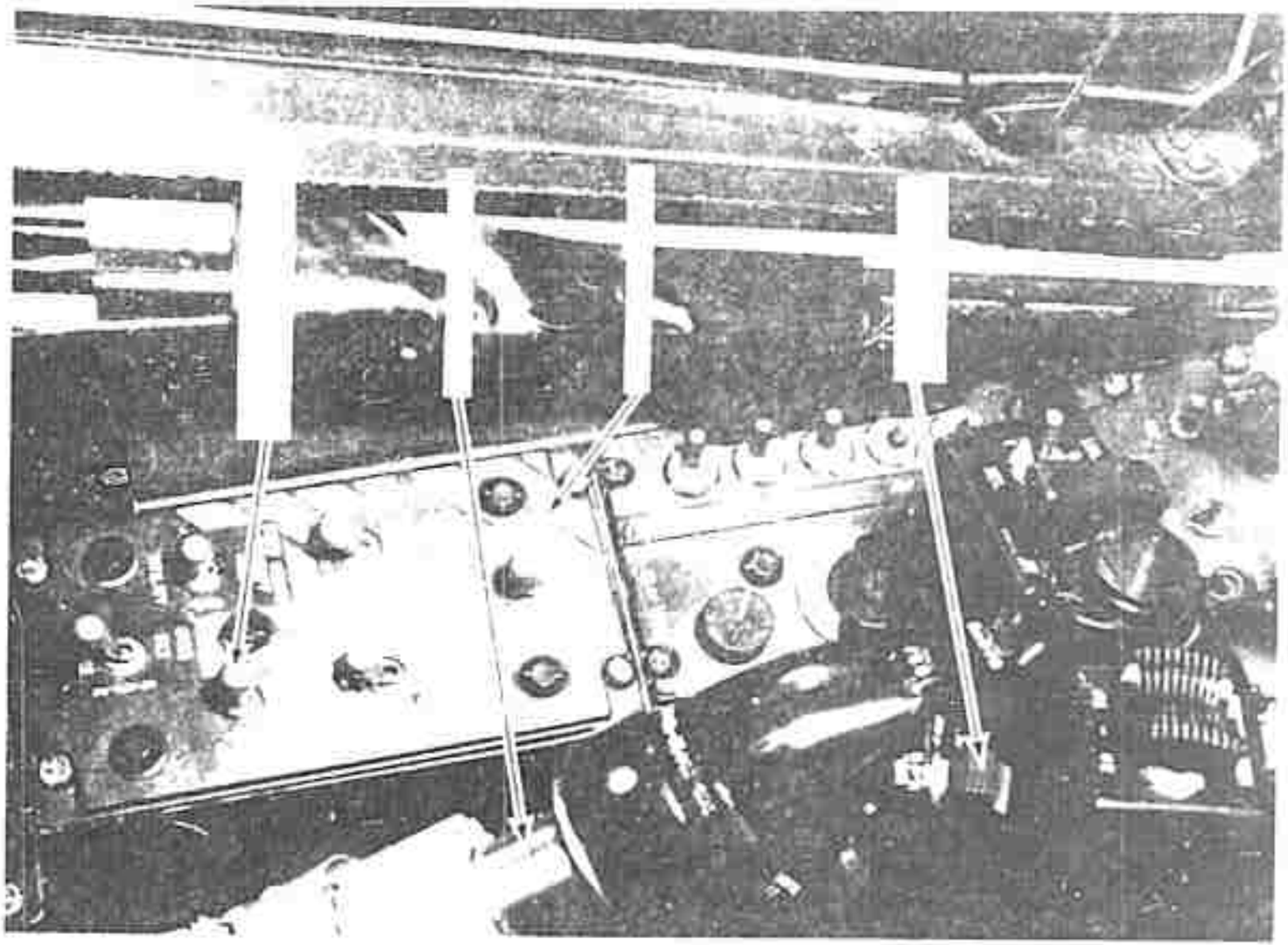
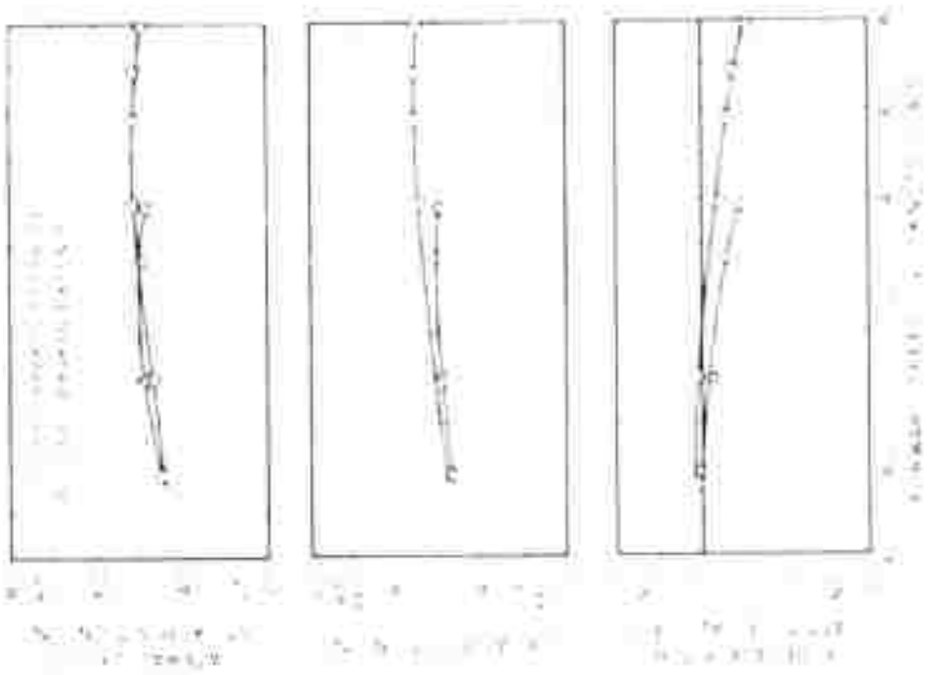
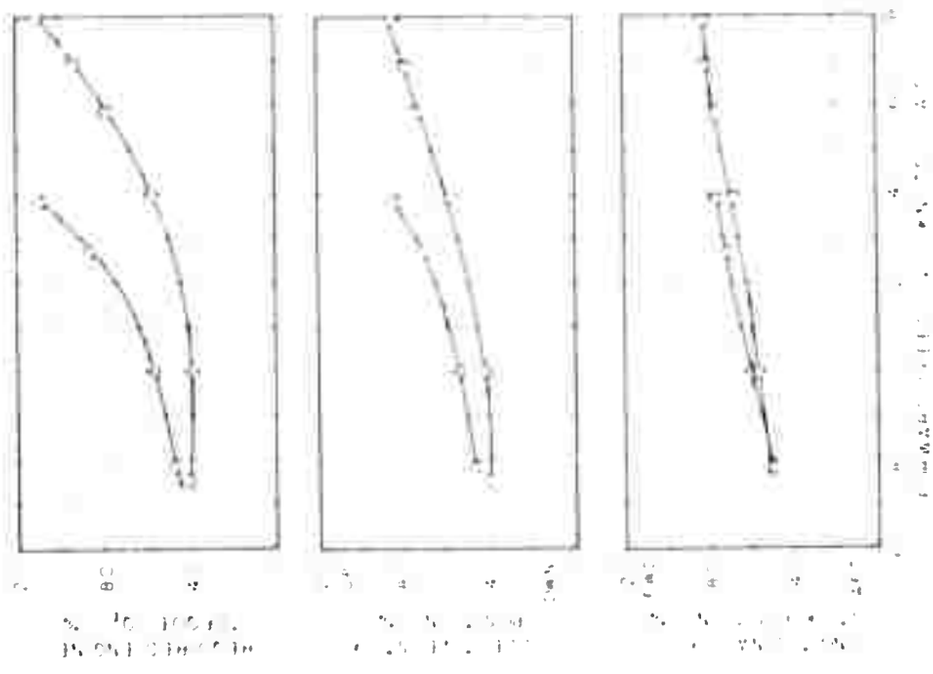
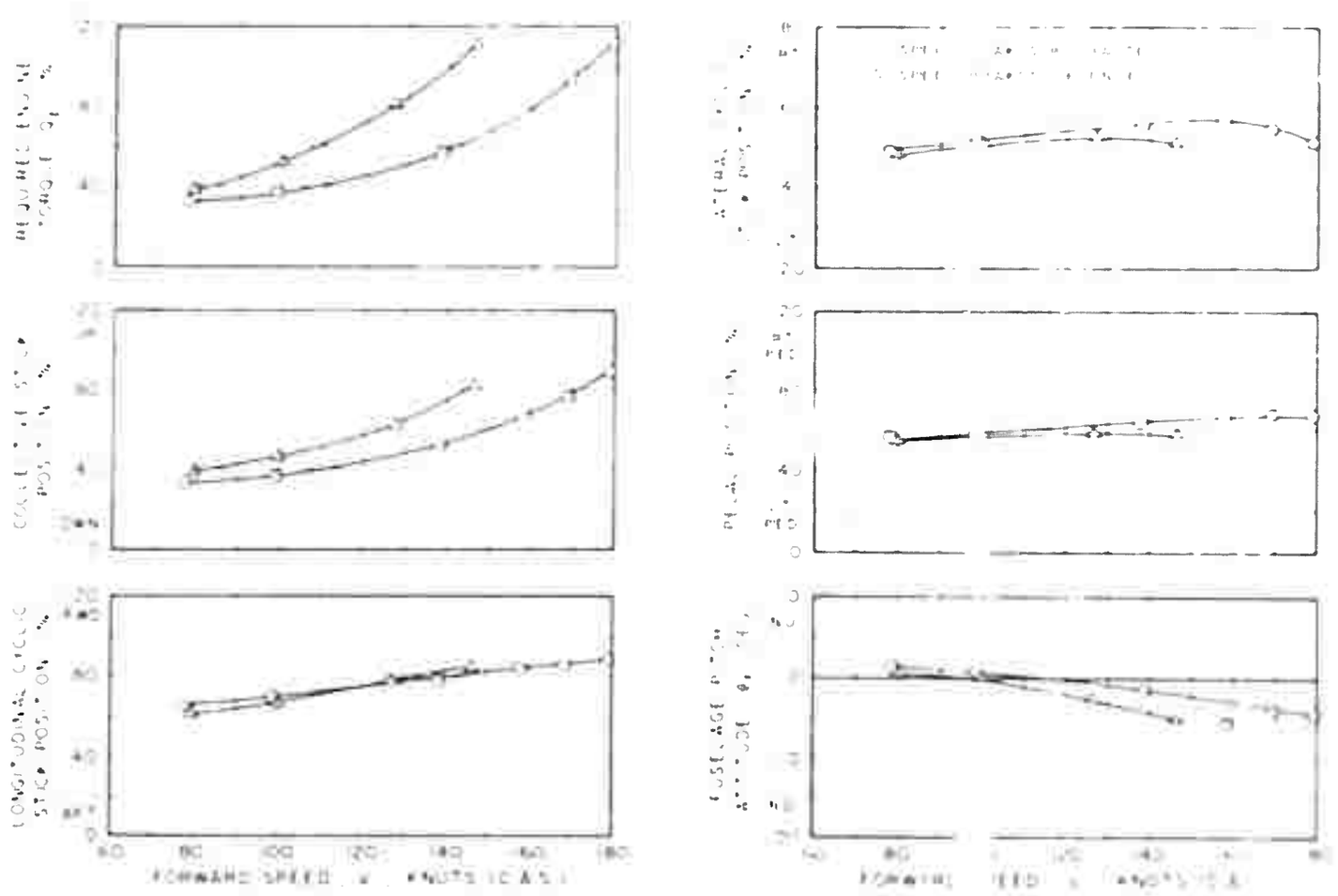


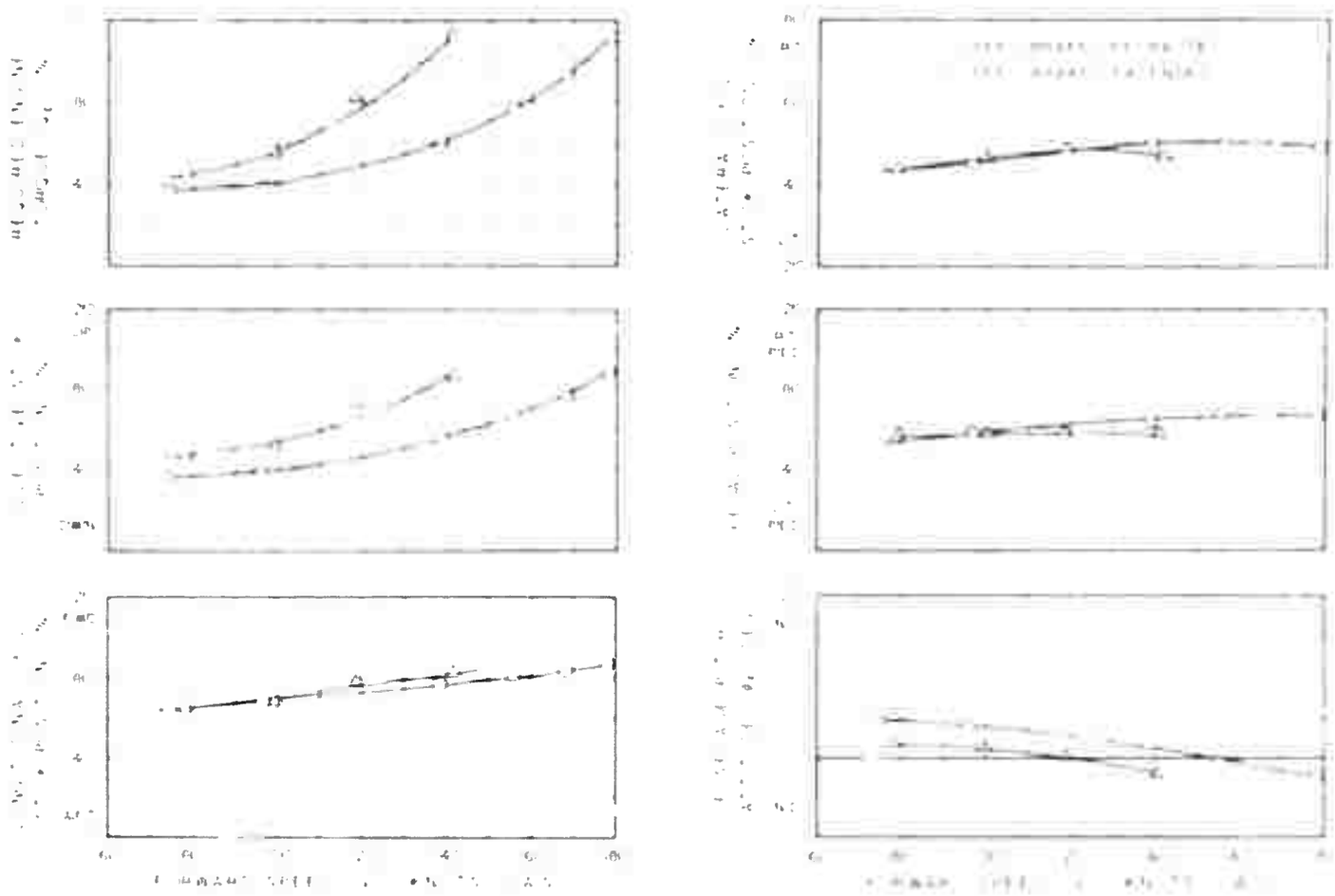
Figure 4. In-Flight Front View, Speed Brakes Extended.

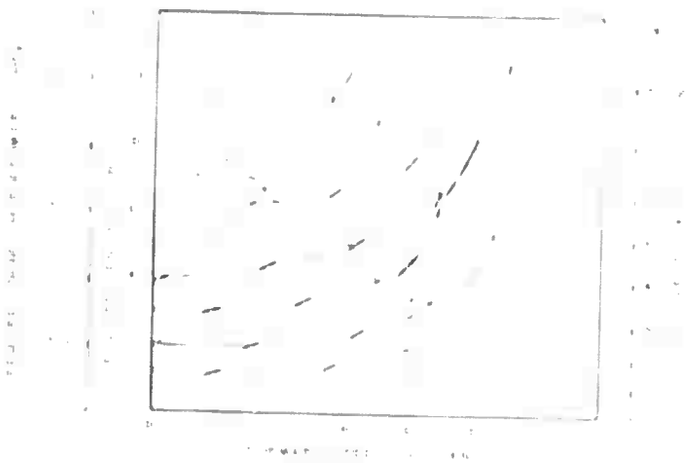


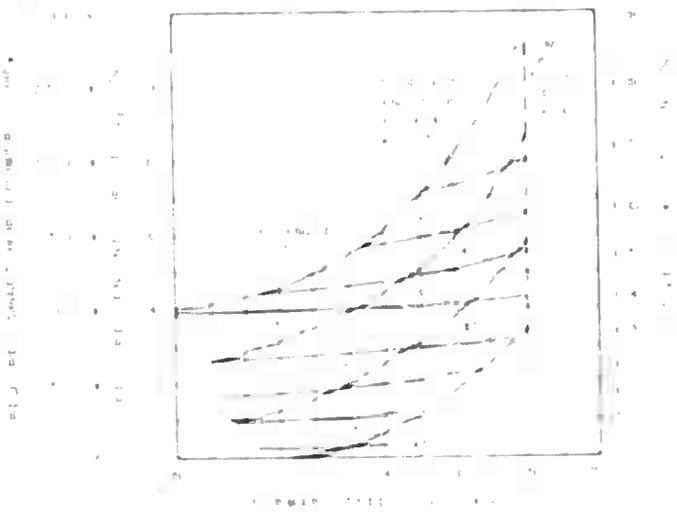


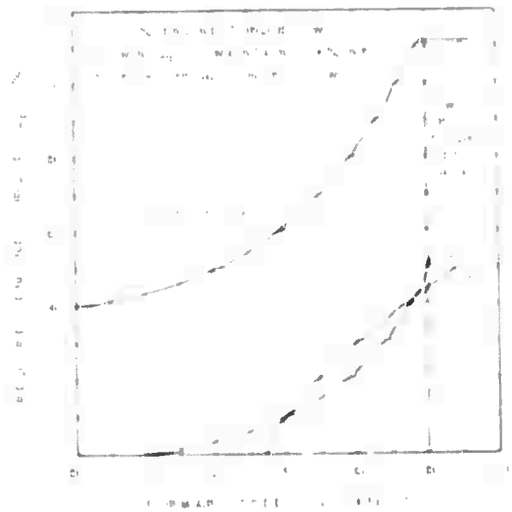












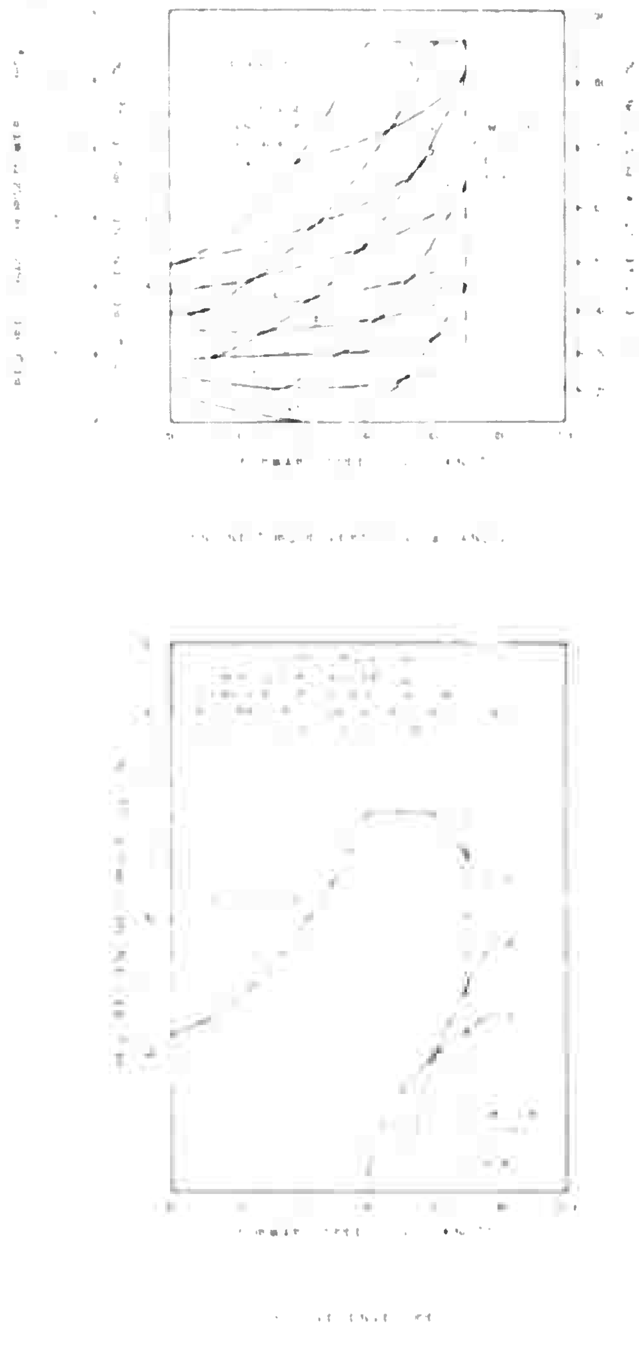
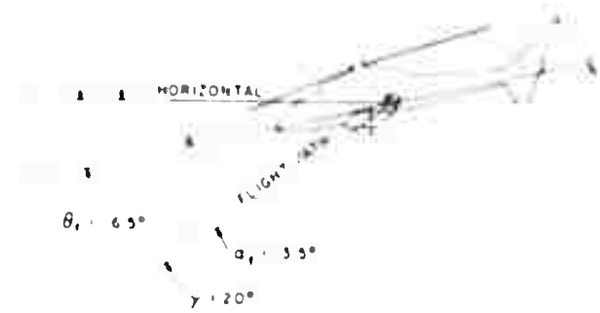
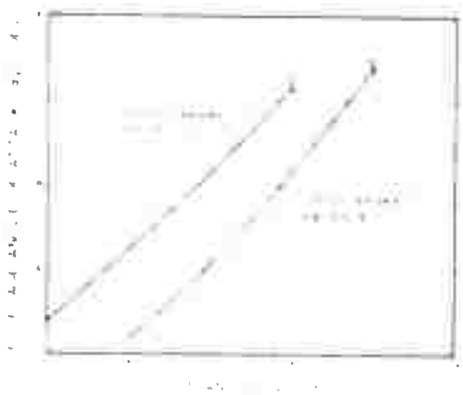


Figure 11. Dive Characteristics, GW = [illegible],300 lb, cg = .7[illegible] in., Speed Brakes Extended.

(a) MAXIMUM DIVE ANGLE, SPEED BRAKES RETRACTED



(b) MAXIMUM DIVE ANGLE, SPEED BRAKES EXTENDED



(c) FUSELAGE ANGLE OF ATTACK VS DIVE ANGLE

Figure [illegible]

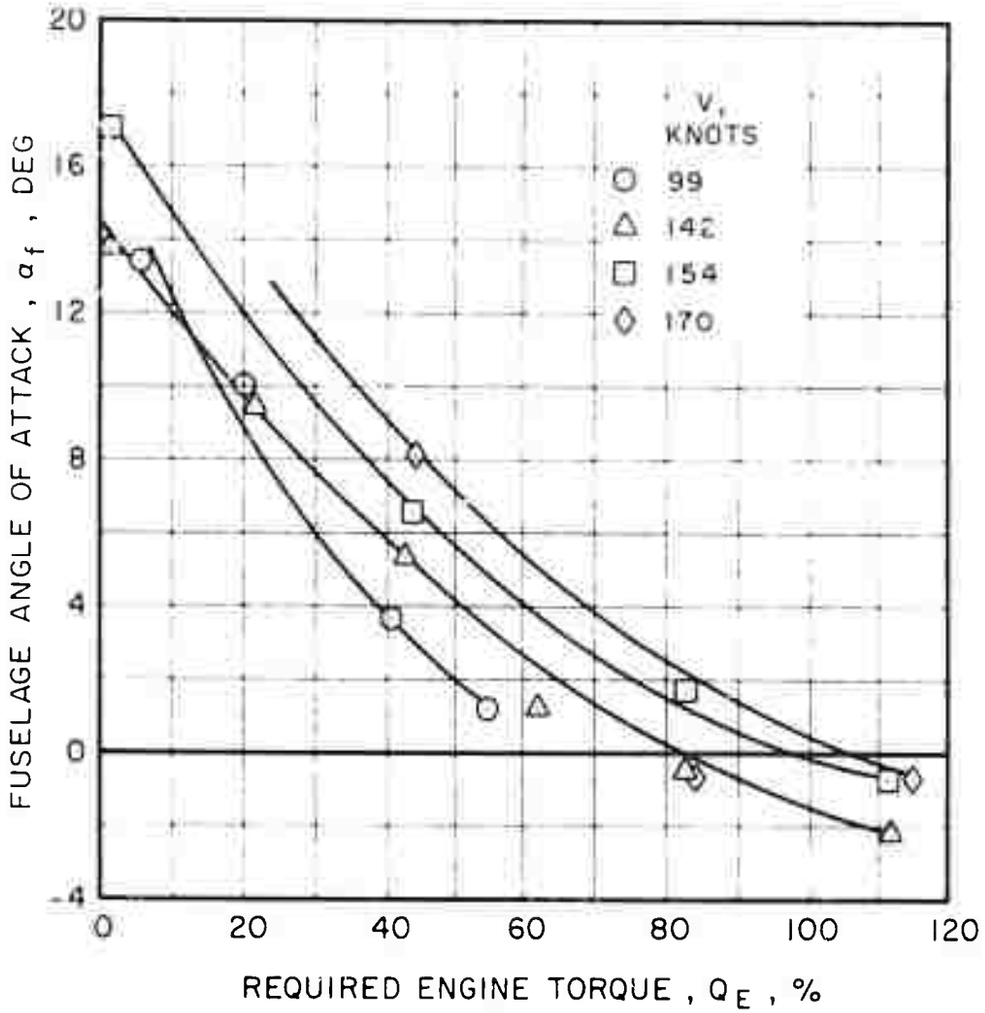


Figure 19. Fuselage Angle of Attack vs. Engine Torque and Forward Speed, W = 17,500 lb, cg = 270 in., Speed Brakes Extended.

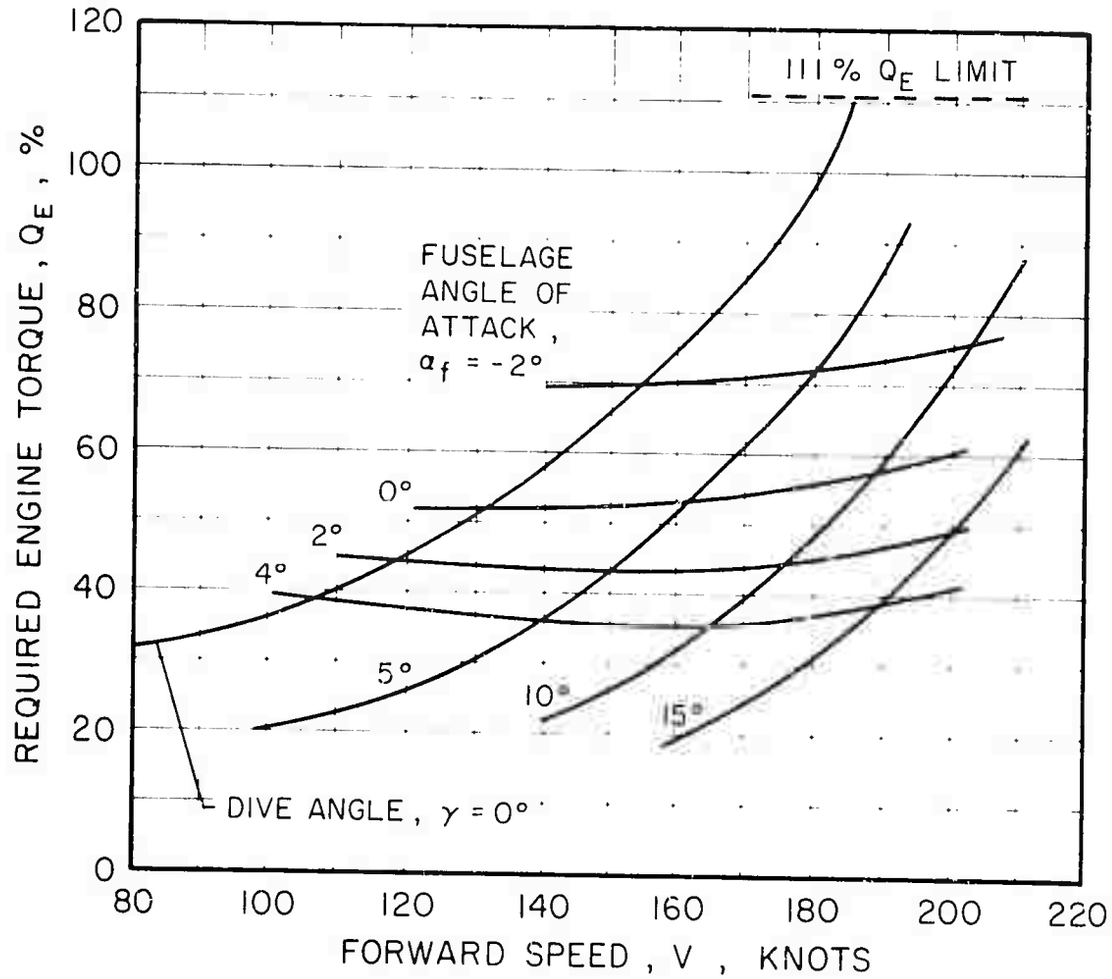


Figure 14. Simulation of Dive Characteristics, Speed Brakes Retracted, GW = 14,800 lb, cg = 276 in.

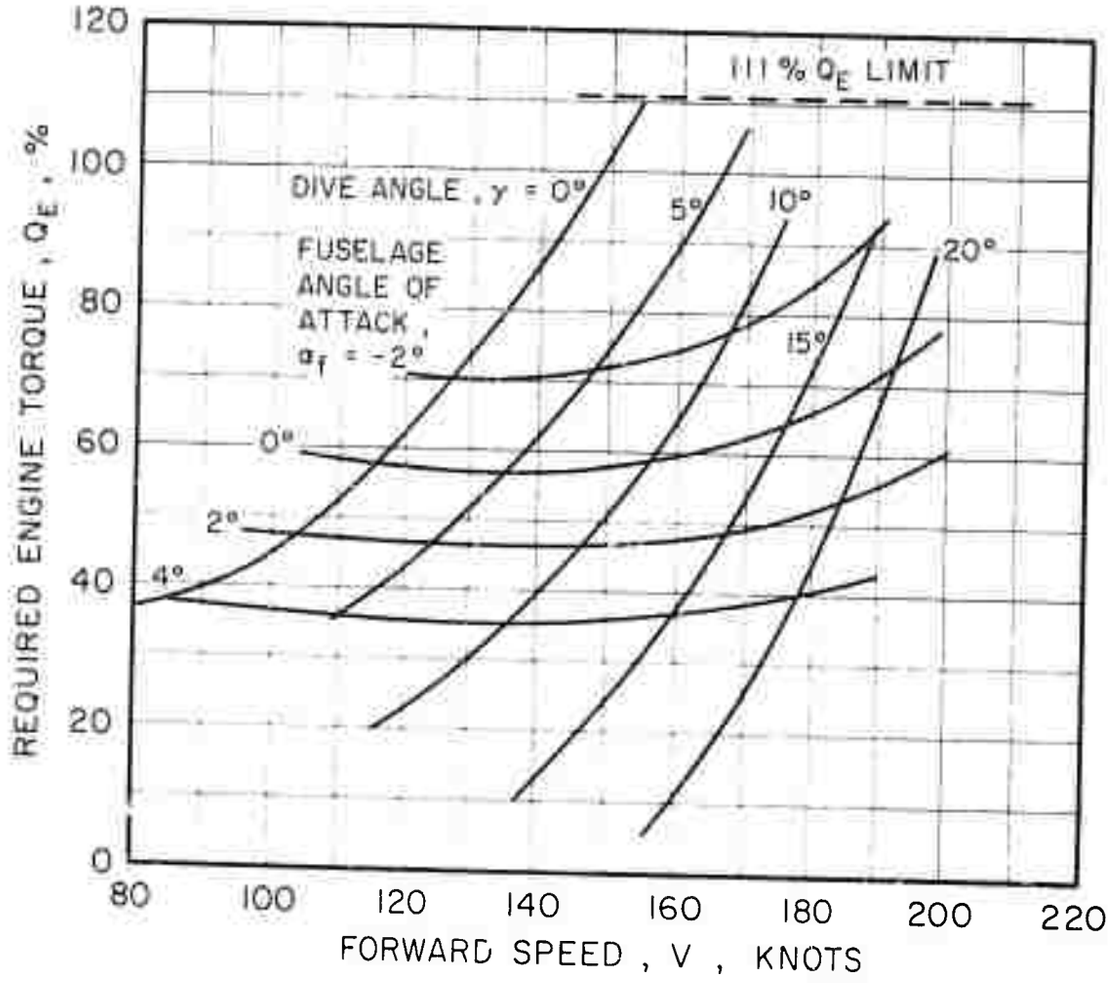


Figure 15. Simulation of Dive Characteristics, Speed Brakes Extended, GW = 14,800 lb, cg = 276 in.

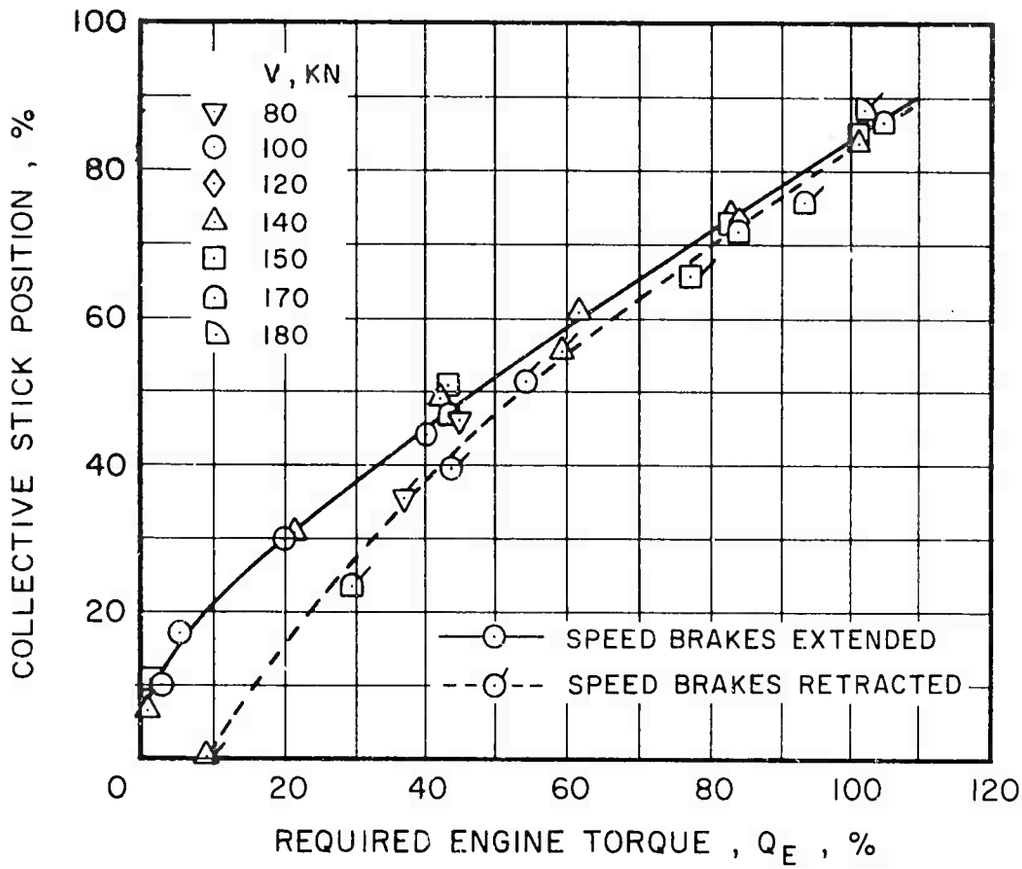


Figure 16. Collective vs. Engine Torque, GW = 17,300 lb, cg = 276 in.

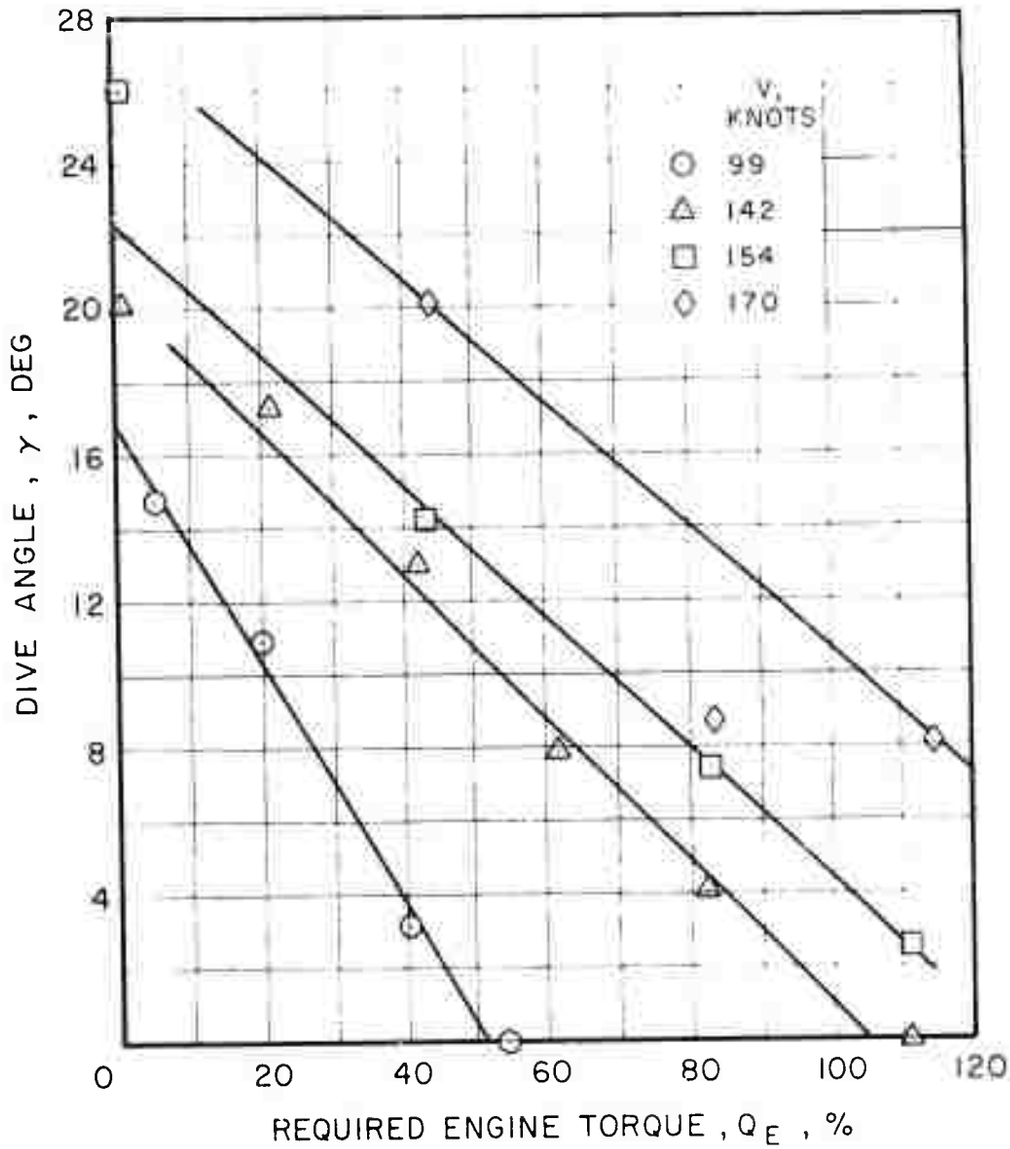


Figure 17. Dive Angle vs. Engine Torque and Forward Speed, GW = 17,300 lb, cg = 276 in., Speed Brake Extended.

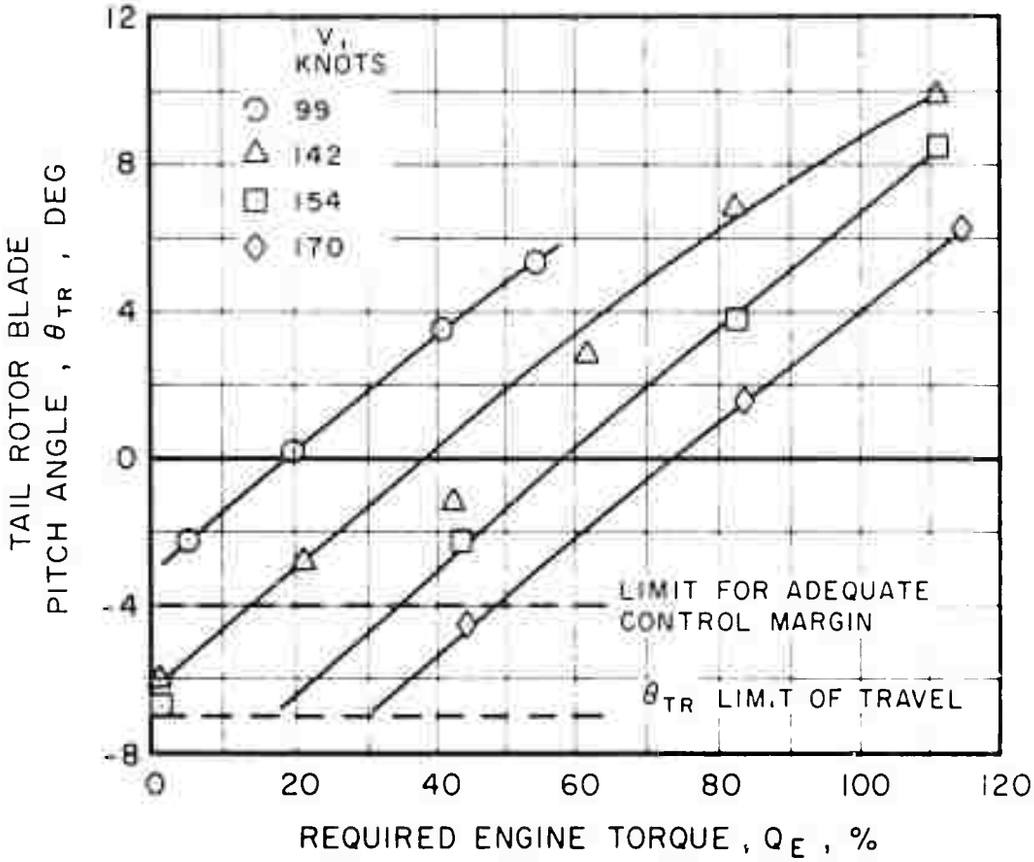


Figure 18. Tail Rotor Pitch vs. Engine Torque and Forward Speed, W = [illegible] lb, cg = [illegible] in., Speed brakes extended.

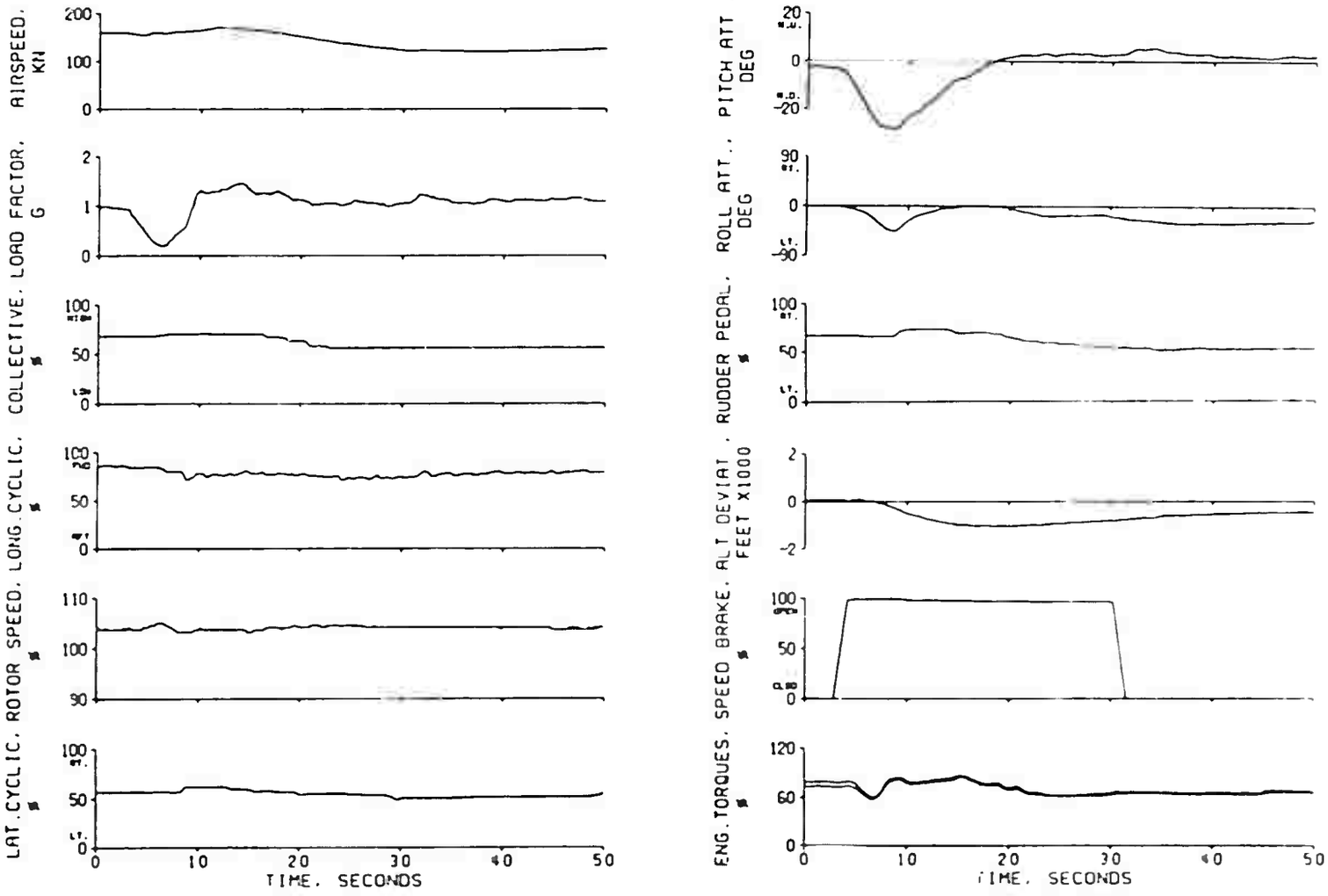
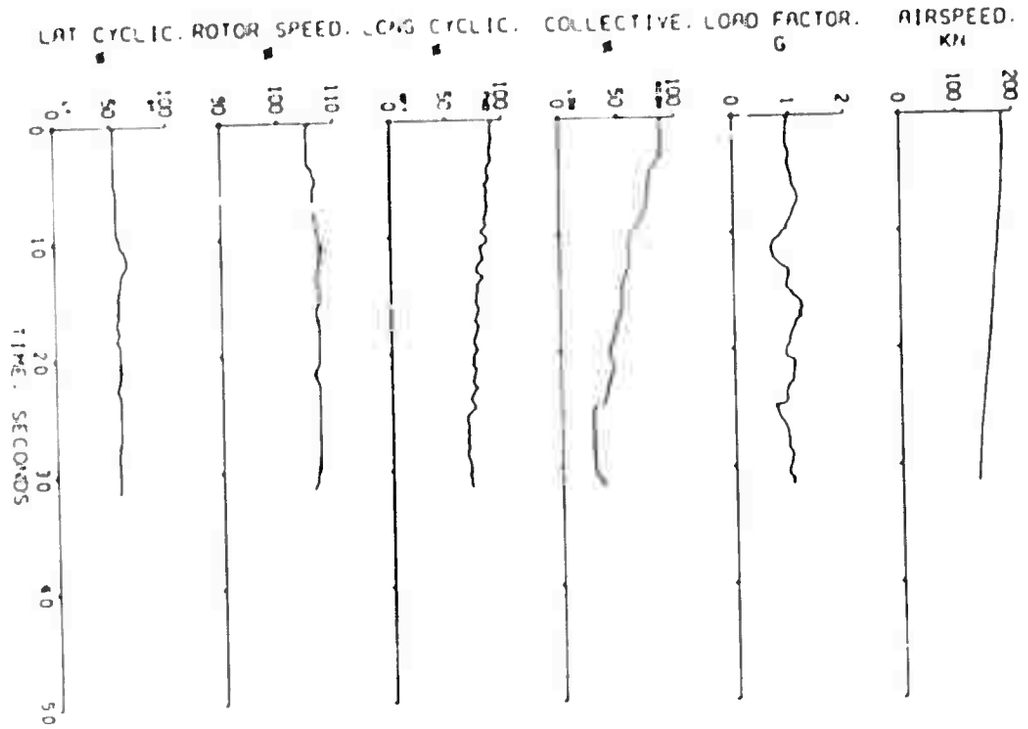
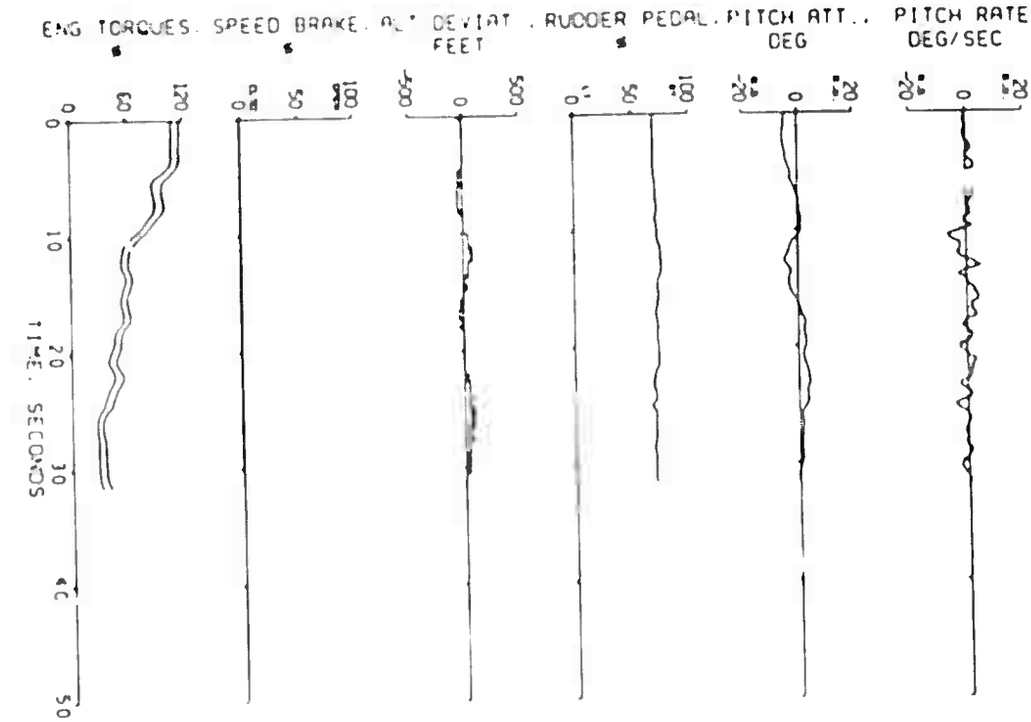
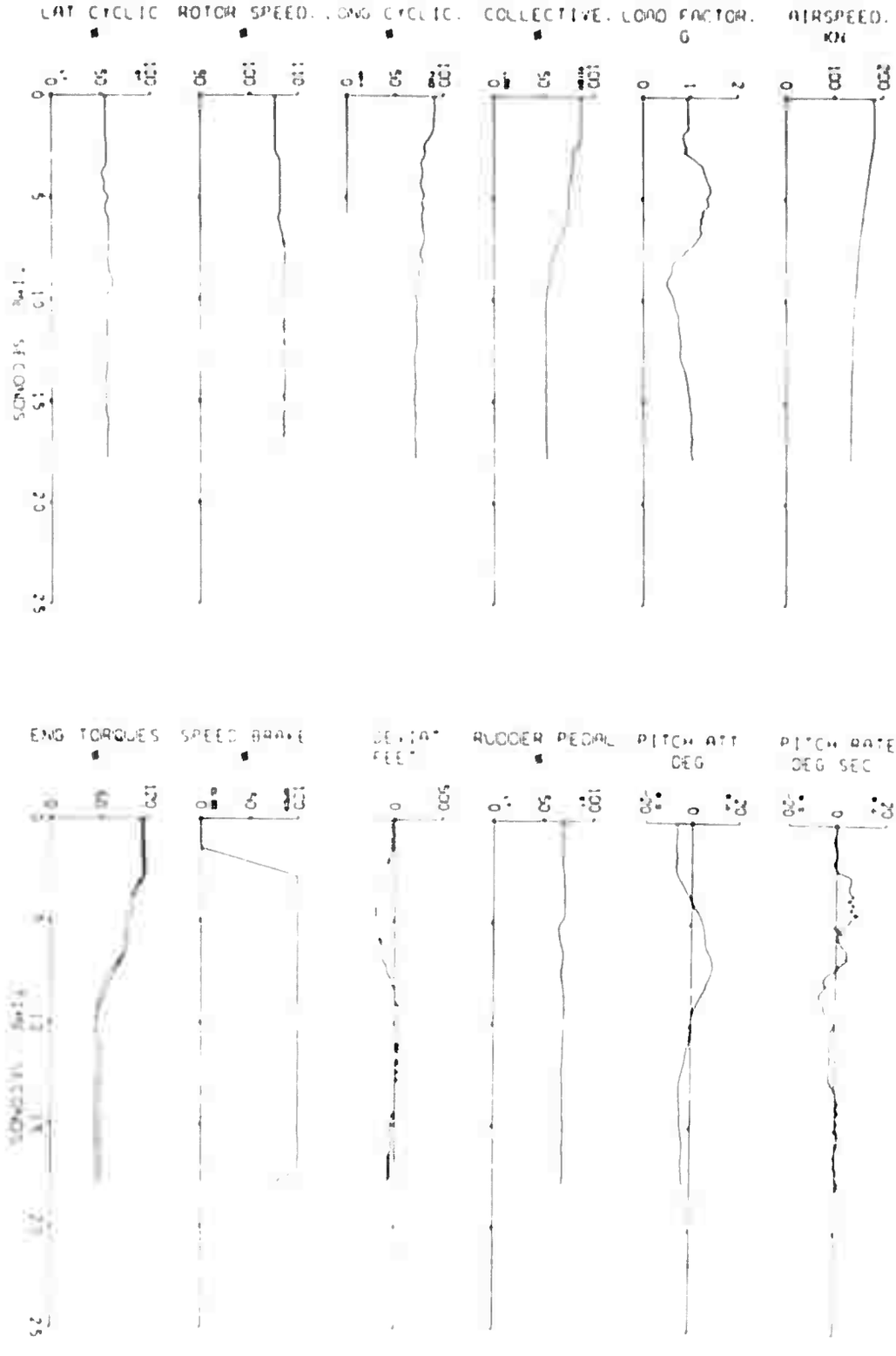


Figure 19. Transient Effects of Speed Brake Extension at V = 180 kt, Controls Fixed.


LAT CYCLIC.
ROTOR SPEED.
LONG CYCLIC.
COLLECTIVE.
LOAD FACTOR. G
AIRSPEED. KN
SECONDS TIME


ENG TORQUES.
SPEED BRAKE.
ALT DEVIAT. FEET
RUDDER PEDAL.
PITCH ATT.. DEG
PITCH RATE. DEG/SEC
SECONDS TIME


LAT CYCLIC
ROTOR SPEED.
LONG CYCLIC.
COLLECTIVE.
LOAD FACTOR.
G
AIRSPEED.
KN
SECONDS Rel.
ENG TORQUES
SPEED BRAKE
RUDDER PEDAL
PITCH ATT
DEG
PITCH RATE
DEG SEC

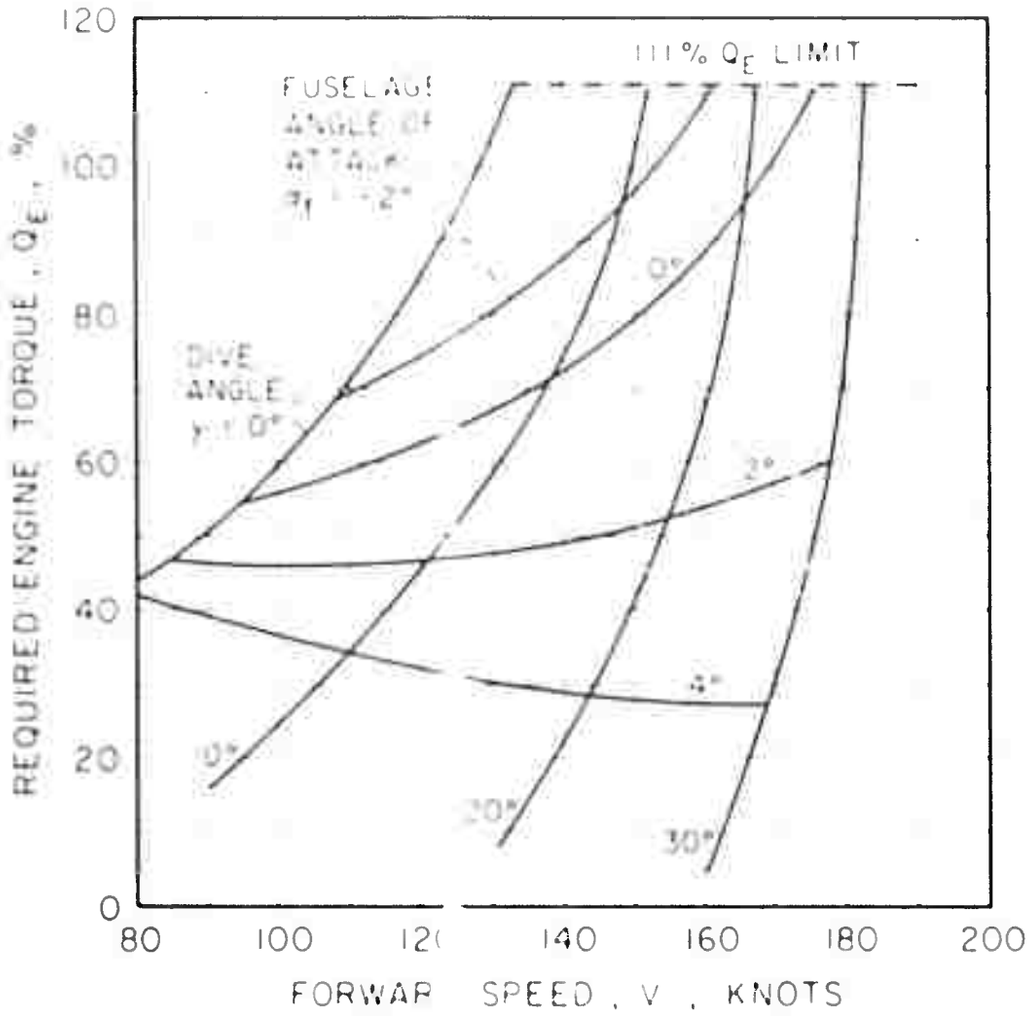
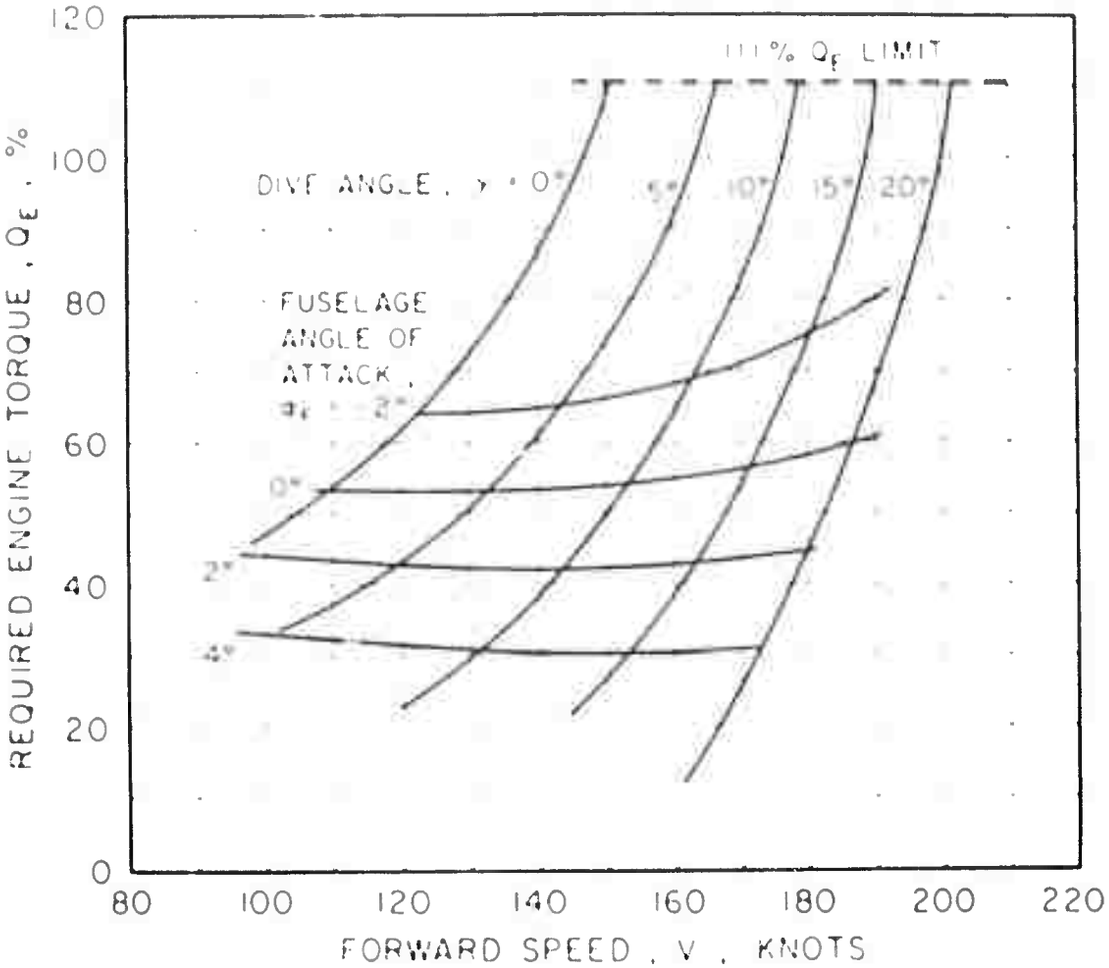
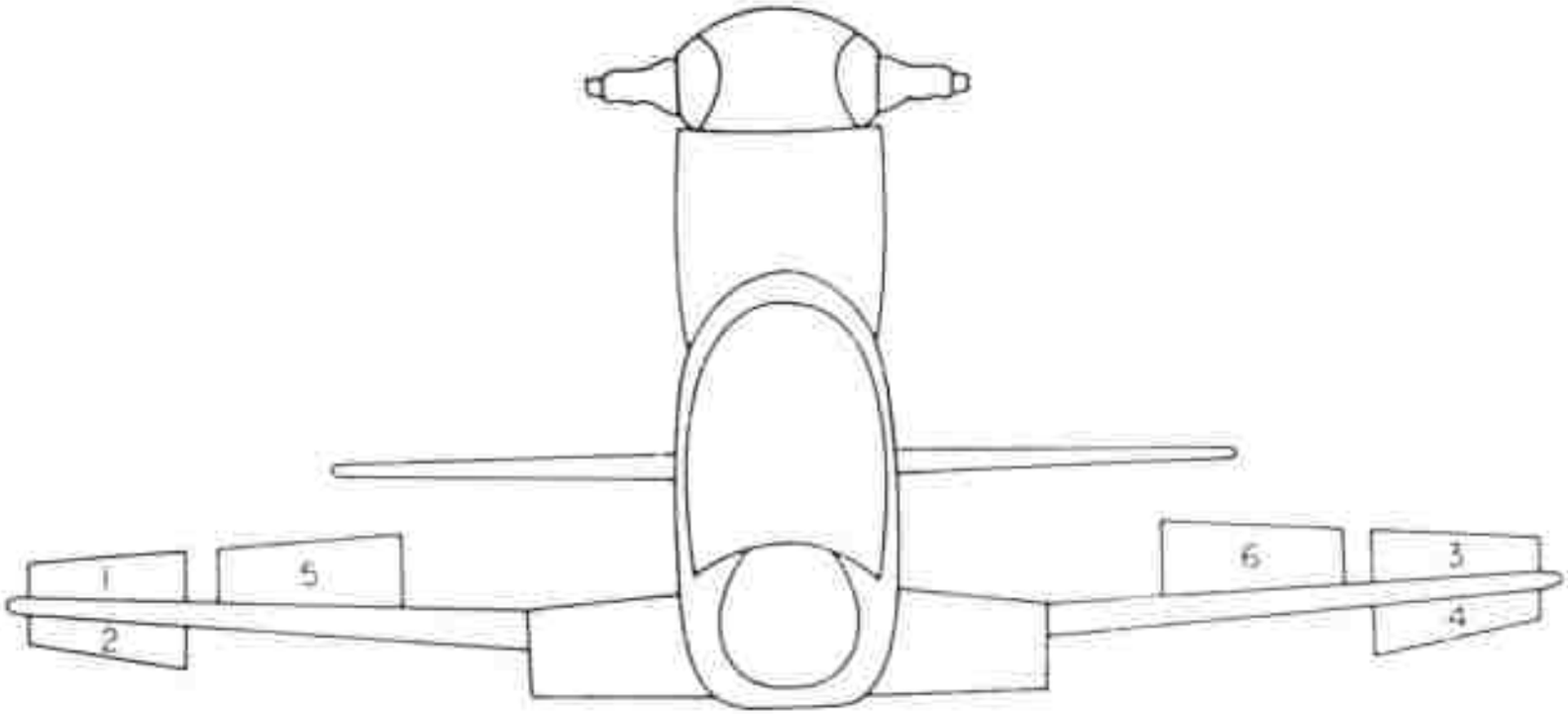


Figure ... [illegible] Dive [illegible] Speed [illegible] Fuselage Angle of Attack.


111% Q_E LIMIT
DIVE ANGLE, γ = 0°
5°
10°
15°
20°
FUSELAGE ANGLE OF ATTACK, α_f
2°
0°
-2°
-4°
REQUIRED ENGINE TORQUE, Q_E, %
120
100
80
60
40
20
0
80
100
120
140
160
180
200
220
FORWARD SPEED, V, KNOTS


1
2
5
6
3
4

APPENDIX I

WIND TUNNEL DATA

Figure 1 shows sample wind tunnel data trace for [illegible] pitching moment $M_{\frac{1}{4}}$, and trace 2 [illegible] parameters are plotted versus [illegible] angle of attack, α_s, of a model [illegible] tested for the basic airframe with [illegible] with wings and simulated brake surfaces added. The brakes [illegible] lift, produced a nose-up pitching moment [illegible] change in $M_{\frac{1}{4}}$, and increased drag area by [illegible] at α_s = [illegible].

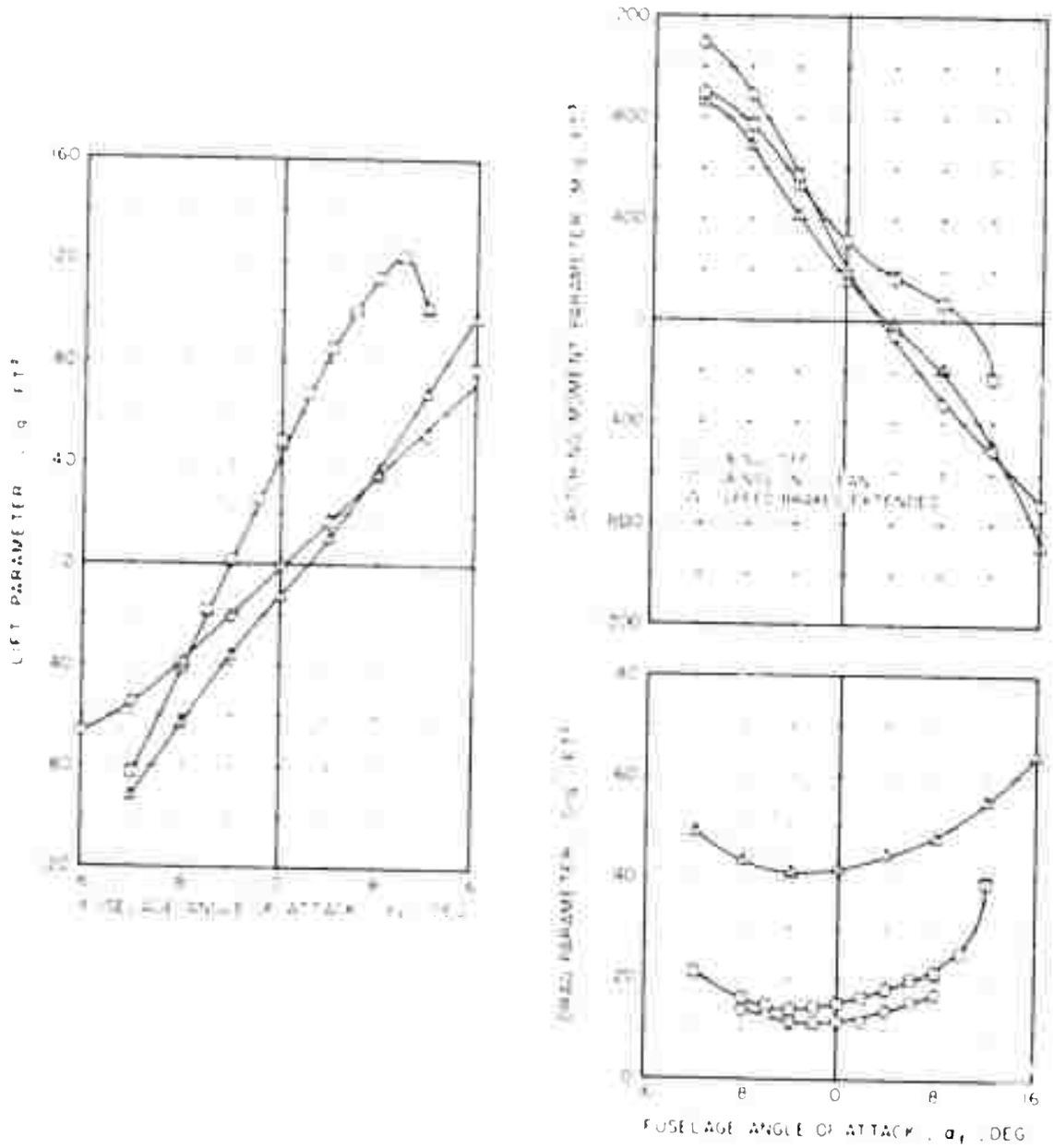


Figure 15. [illegible] Wind Tunnel Data, Showing Lift, Pitching Moment, and Drag vs. Fuselage Angle of Attack for Total Aircraft Less Wings, With Wings, and Speed Brakes Retracted and Extended.

APPENDIX II

COMPUTER SIMULATION STUDY

DESCRIPTION

The General Helicopter Simulation Program described in Reference 4 was adapted to Sikorsky Aircraft's PDP-10 digital computer to simulate the S-67. The six-degree-of-freedom simulation used a rotor model with a rigid five-bladed four-segmented blade element analysis including the rotor flapping degree of freedom. Nonlinear steady-state rotor blade airfoil section aerodynamic data were used that include the effects of stall and compressibility. Two-dimensional flow was assumed at each section of the blade.

Wind tunnel data from a one-twelfth scale model test of the S-67, Reference 1, were used to describe the force and moment contributions of the combined wing, fuselage, stabilator, and vertical tail. Speed brake contributions to the aircraft forces and moments were incorporated as additional components to those for the basic aircraft. The wind tunnel data included the effects of aircraft angle of attack and stabilator incidence on lift, drag, and pitching moment.

CORRELATION WITH FLIGHT TEST DATA

Hover

In hover, two adjustments to the simulation were necessary to obtain satisfactory correlation. Main rotor blade twist was increased by 2 degrees, and a 2-inch lateral center-of-gravity shift to the left was applied at the light gross weight conditions.

The S-67 rotor blades show some degree of aerodynamic twisting with the 20-degree swept tips. Under normal trimmed flight conditions, the blade loadings are high at the blade tip. Since the center of pressure of the swept tip is behind the blade torsional axis, aeroelastic twisting results.

The lateral center-of-gravity offset to the left brought the trim lateral cyclic requirement into agreement with flight test data. This center-of-gravity offset is expected, since the tail rotor and the vertical tail are positioned to the left of the aircraft centerline.

Forward Flight

In forward flight, the blade aerodynamic twist correction for collective pitch correlation varied with speeds above 80 knots. Above this speed the correction diminished linearly to -0.5 degree at 182 knots. A leading-edge-up stabilator bias angle correction of 2 degrees was needed to correlate longitudinal cyclic and aircraft attitude. This is due to some inaccuracies in predicting main rotor downwash at the stabilator.

Figure 26 shows the results of the correlation in hover and forward flight for the light-gross-weight aft-center-of-gravity condition, with speed brakes retracted and zero stabilator bias angle. Specific flight test points were simulated using the proper gross weight and density altitude. From hover to 80 knots, the simulation points are connected by a dotted line to indicate that no correlation was attempted in the low-speed regime.

At high speed, the rotor model requires extremely high power at moderate rotor stall. This is because two-dimensional flow at the rotor blade section was used, omitting the spanwise component.

To correlate flight test values of longitudinal cyclic and aircraft pitch attitude in forward flight with speed brakes extended, a reduction in the pitching moment was necessary, equivalent to that produced by 9 square feet of drag area. The wind tunnel model speed brakes were fixed flush to a solid wing, whereas the extended brakes on the S-67 leave a hole through the wing and a 1-inch slot between the brake panel and the wing, as shown in Figure 2. The resulting aerodynamic inconsistencies between wind tunnel and flight test conditions, and the shortcomings of the rotor model mentioned above, hindered exact simultaneous correlation of aircraft attitudes, control quantities and rotor power in level flight.

Figures 27 through 29 show the results of the correlation for different gross weights, center-of-gravity positions, and stabilator biases.

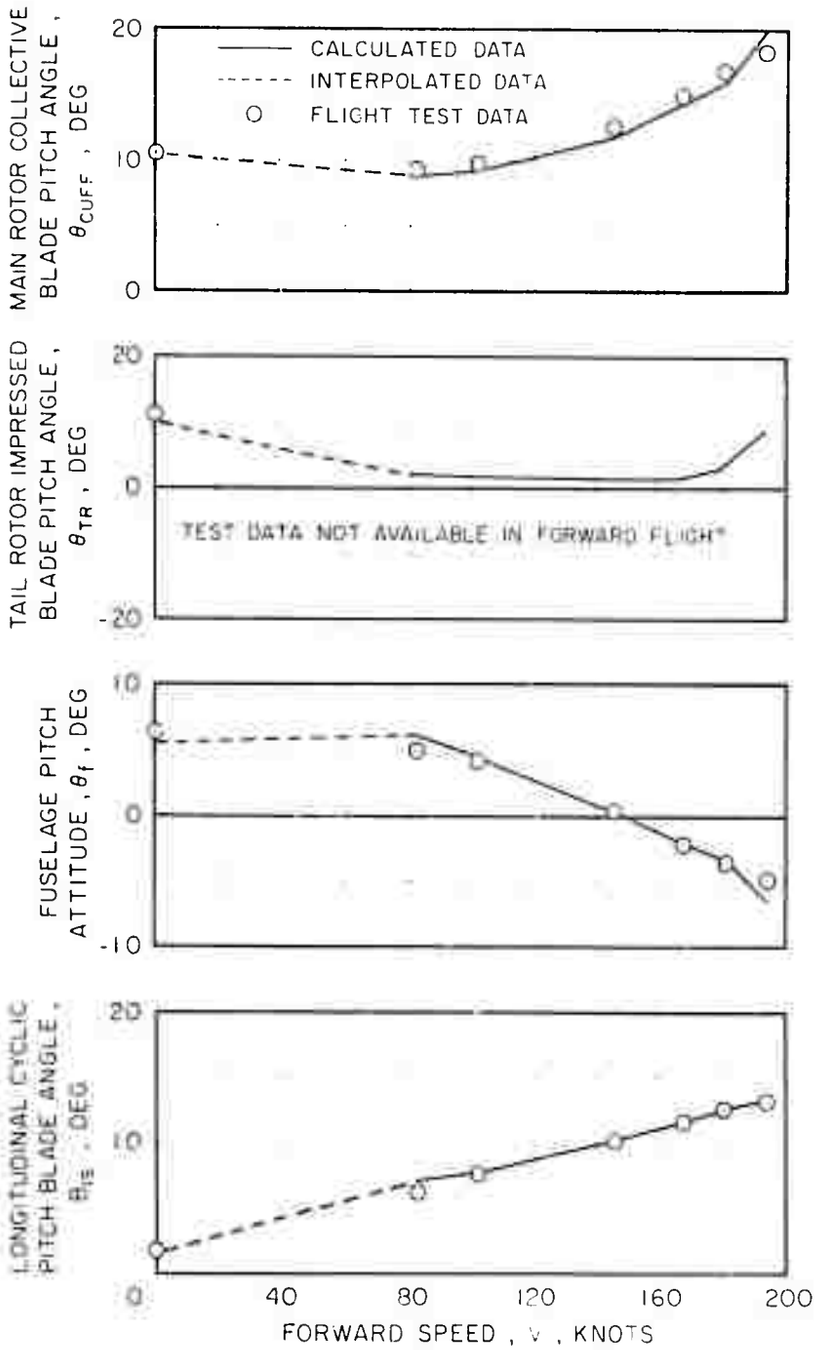


Figure 26. Comparison Between Simulated and Flight Test Data, Level Flight Trim, GW = 14,000 lb, cg = .76 in., Stabilator Bias = 0 deg, Speed Brakes Retracted.

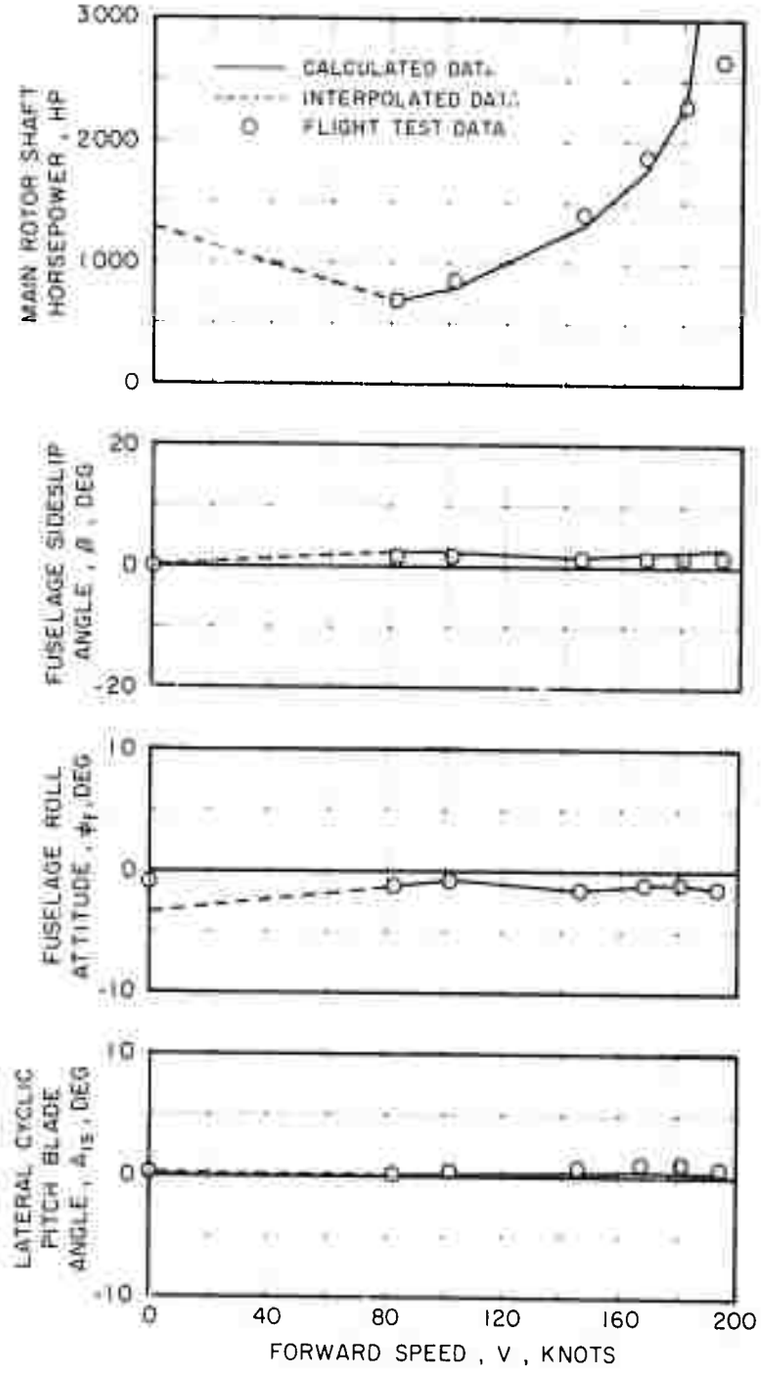


Figure 26. Concluded.

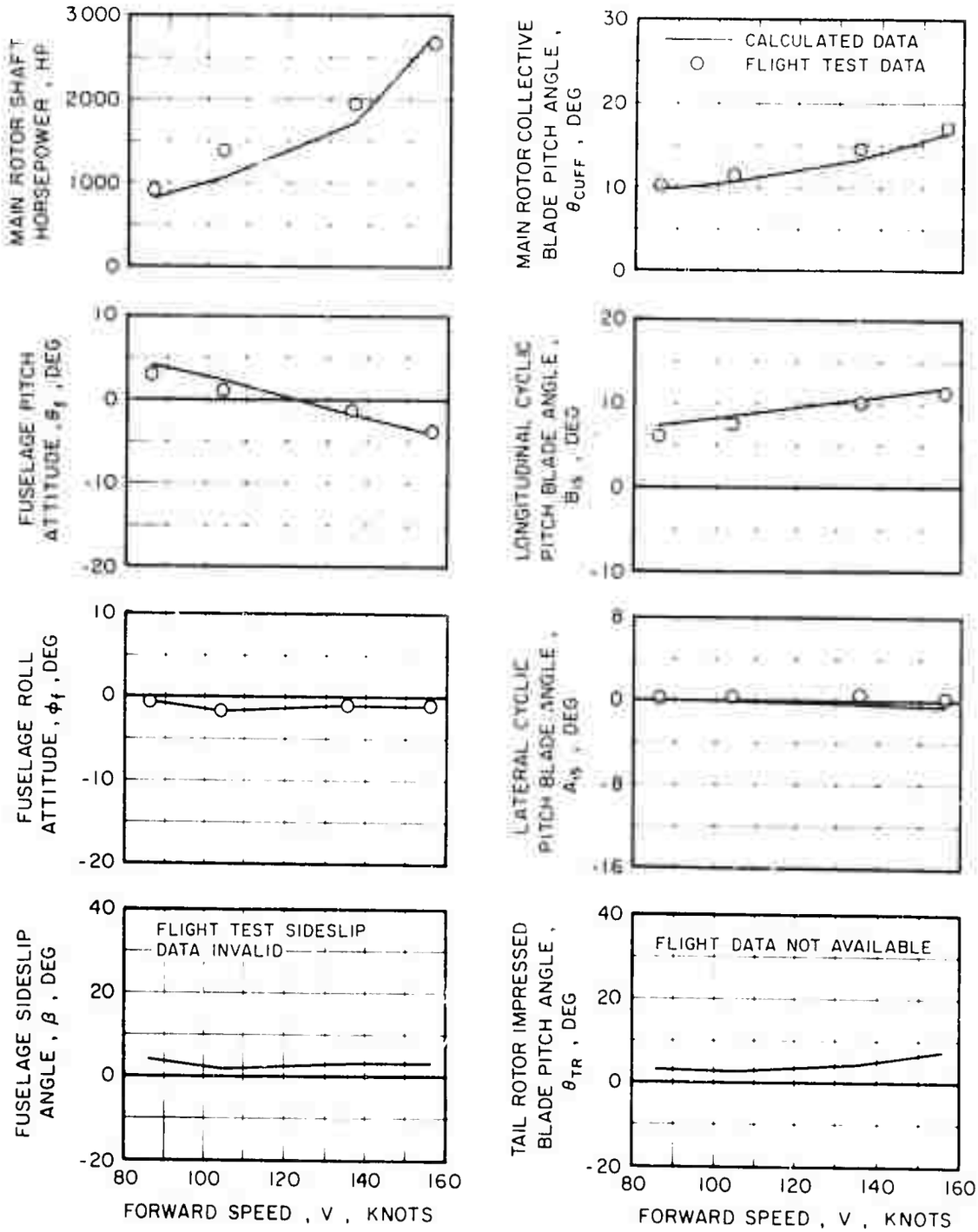


Figure 27. Comparison Between Simulated and Flight Test Data, Level Flight Trim, GW = 14,500 lb, cg = 275 in., Stabilator Bias = 0 deg, Speed Brakes Extended.

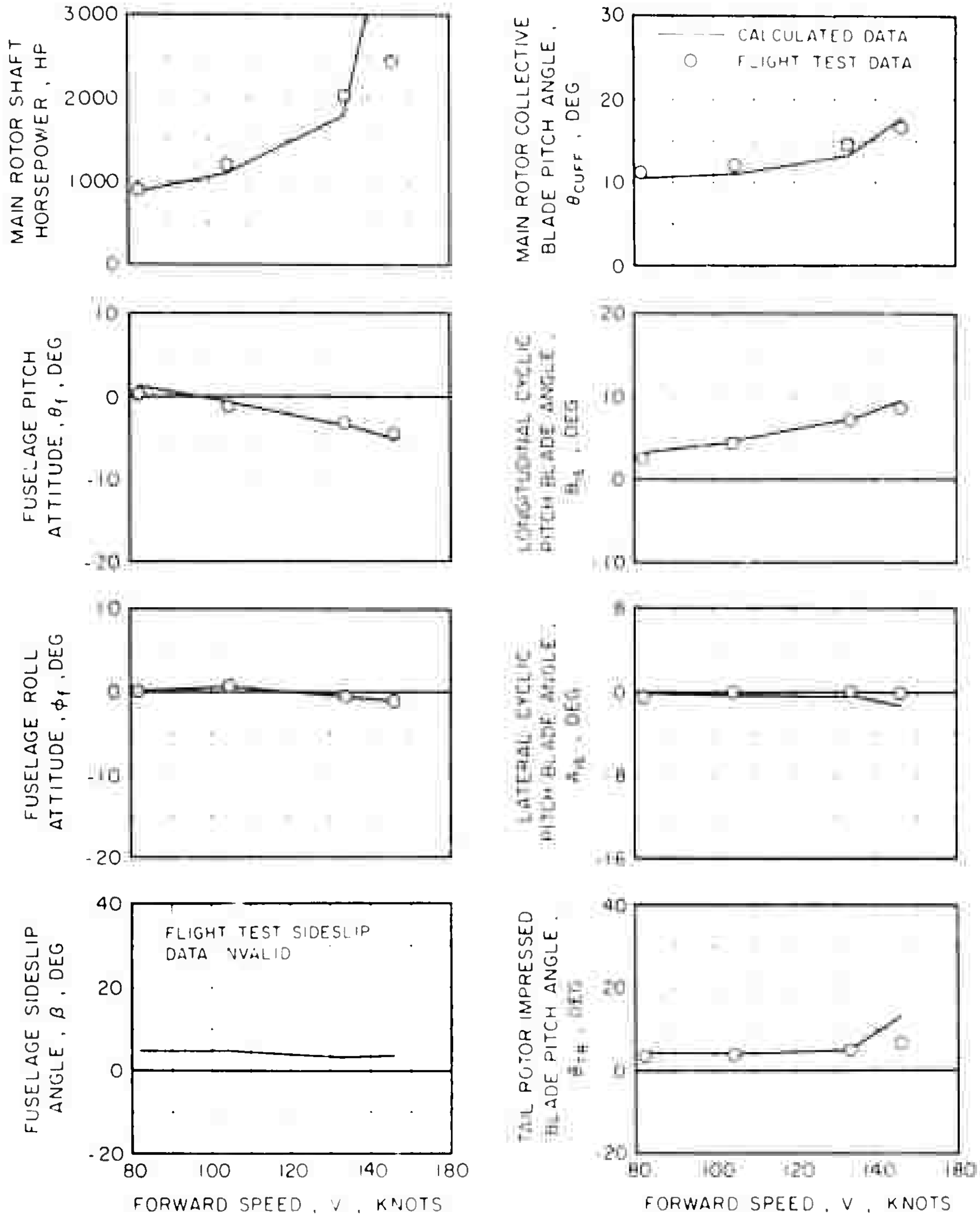


Figure 28. Comparison between Simulated and Flight Test Data, Level Flight Trim, GW = [illegible] lb, [illegible] = [illegible] in., Stabilator Bias = [illegible] Deg, Speed Brakes Extended.

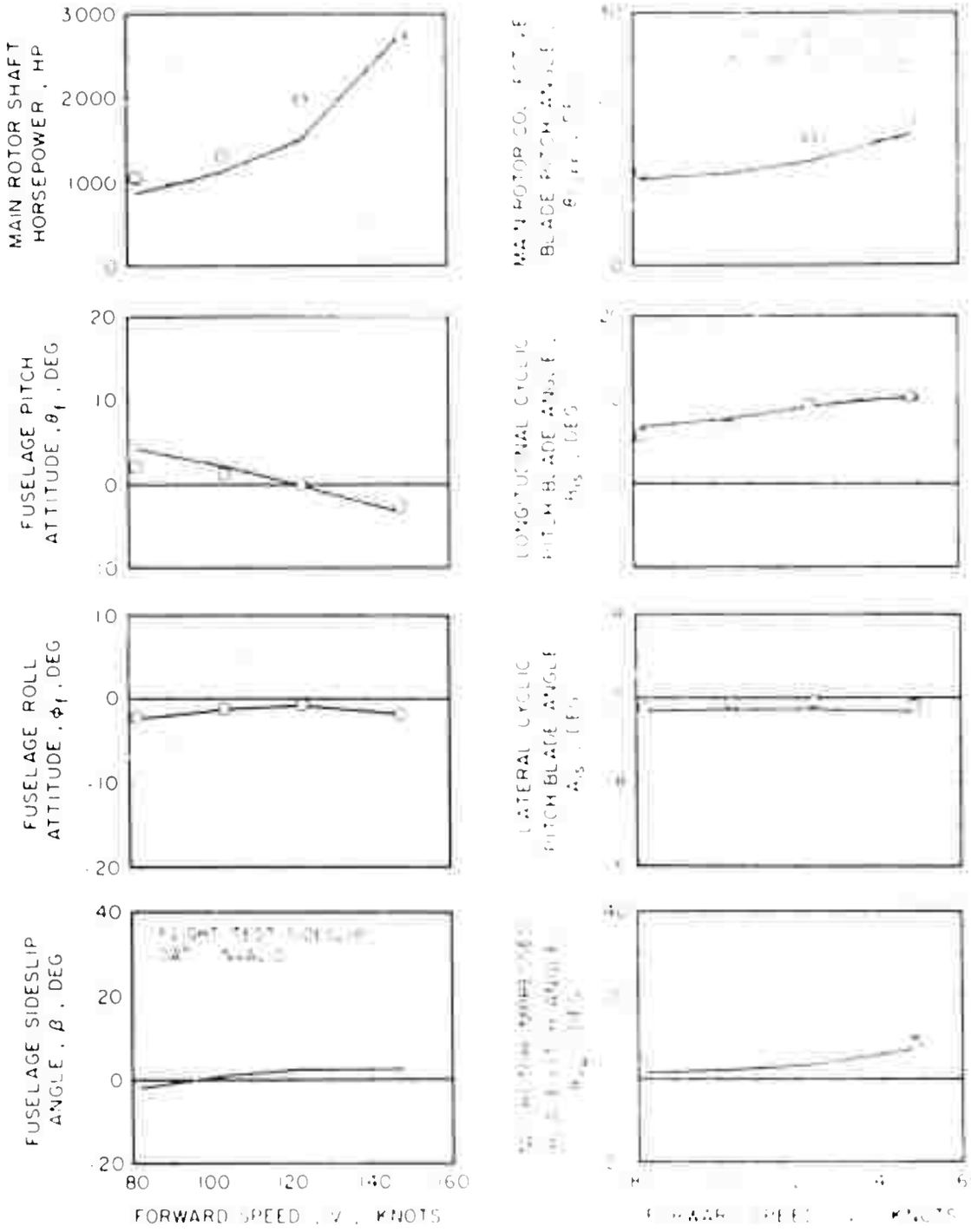

MAIN ROTOR SHAFT HORSEPOWER, HP
3000
2000
1000
0
FUSELAGE PITCH ATTITUDE, θ_f, DEG
20
10
0
-10
FUSELAGE ROLL ATTITUDE, Φ_f, DEG
10
0
-10
-20
FUSELAGE SIDESLIP ANGLE, β, DEG
40
20
0
-20
80
100
120
140
160
FORWARD SPEED, V, KNOTS

Figure 29.